DESIGN AND IMPLEMENTATION OF MANUAL ASSEMBLY CONTROL SYSTEM

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INTRODUCTION:

The following project, is the redesign of a former project ordered by a company to the writer of this project, which wasn't totally successful on the first try, so it was a challenge to find the way to make the system more robust and reliable, as close as possible to a real commercial product.

In this project, there are three main fields which will be combined along it, electronics, mechanics and programming. The mechanical design part, which was the main handicap of the designer during the development of the project in which is based the following, will be greatly improved. Also there was an improve in the electronic design skills, but over this, the research and component identification of the designer have improved during the period of time between the development of the old and the new project. Probably the part in which the designer didn't improve enough to mean a notorious change from the former project, is the programming, but anyway the process of redesigning the system had as a consequence in the designer to find a new way of thinking about the programming problems and how to approach them.

It's important to note also the skills acquired regarding to the acquisition of materials, and the relations with the providers.

1. PROJECT JUSTIFICATION:

1.1 BACKGROUND:

In several times , there were errors in the products acquired by the customers of the company for which this system is being designed. Despite those errors are not big failures, they result in products that must be replaced, with the consequent damage to the image of reliability of the company, and the confidence of the customers on it.

Currently there is not any control system to identify any possible error in the manual assembly process done by the workers.

Taking in consideration, the company for which this project is being built, wants to keep the defect ratio under 10 parts per million, it's important to keep all the possible sources of error, as controlled as possible, justifying on this manner, the following project.

1.2 PROBLEM DEFINITION:

Due to the lack of a control system on the manual assembly process, some distractions made by the assembly workers, could give as a result, apparently correct assemblies, not possible to be detected in the critical quality controls, but which can, in a short period of time end up in a malfunction, giving as a result a problem in the offered services to the final customer.

1.3 JUSTIFICATION:

To avoid the previously mentioned problems, and being able to guarantee better quality and reliability to the customer of those assembled products (in the present case, gearboxes) the perform of a control system on the parts the assembly workers utilize during the assembly process is a must, ensuring any part is skipped or assembled in incorrect order. Through this, the defective product ratio will improve, improving also the productivity, and the customer satisfaction.

1.4 TARGETS:

The targets of the current project are the following:

- Design the sensor system able to detect the movement of a hand inside the specified boxes.

- Design the system to couple such sensors in a reliable way, to the specified boxes.

- Design the electronic circuitry needed in order to make the sensors work properly.

- Design the software needed in order to make the sensors work properly.

- Design the interface to connect such sensor system to a console, which will control the overall assembly system.

- Design the console circuitry.

- Design the console software, in a such way that is intuitive and easy to use.

- Design the shape of the console in such way that is compact and reliable.

- Design an I/O interface, to be able to change the configuration of the system.

- Manufacture of a prototype.

- Write a User Manual.

- Provide technical support to the company whom acquires the system.

1.5 SCOPE AND LIMITATIONS

The scope of this project will be the utilization of the system in the assembly process inside the assembly facilities of the company.

This system is not intended to be used outdoor.

This system is not intended to be used in areas with high ambient particles level (like milling/machining facilities).

This system is a PROTOTYPE, so it may need further modifications to work properly, but needs to be tested on the field for a long time to let the possible problems arise.

1.6 STRUCTURE

This project will be mainly divided into three different fields of interest:

- Electronic design.

- Mechanical design.

- Software design.

But will also include some other sections, but related in some way with those previously mentioned topics, as the following:

- Prototype and mass production.

- System testing.

- Mechanical drawings.

2. MECHANICAL DESIGN:

2.1 INTRODUCTION:

Regarding to the mechanical design , the system has two differentiated parts, with their own targets and limitations, the console and the controller.

Talking about the controller, the main needs are to design the housing to contain the sensors, and the control logic unit, in a way that they get adapted to the chosen container, minimizing the impact on the inherent functionality of the container, and letting use the added functionalities with ease, and this means:

- Create a design which doesn't need to modify the container itself to be used.
- Design the housing on a way that adapts naturally the shapes of the container.
- Optimize the form factor.
- Allocate the connectors to the console in a way that allow easy access, avoiding to disturb the normal workflow.
- Create a design which is easy to assemble and disassemble.

But also other needs as creating a mechanically robust design, which protects the sensors, and to design on such way that the parts are easily manufacturable in long scale.

Moving now to the console, which is holding the human-computer interface, the requirements are quite different, taking in consideration it doesn't need to get adapted to an already existing external component. The priority on this case, is the ease to use, meaning that the following:

- Locate the input devices in a way that is easy to access and use.

- Locate the output devices in a way they are easy to read, to provide the required feedback.

- Give easy access to the connectivity to the controllers, as to the system output.

- Contain the electrical net connectors and switches to switch on and off the system.

Same as housing the power supply and the electronic circuitry related with the console, and as in the case of the sensor housings the manufacturability will be taken in consideration.

2.2 SOFTWARE:

The software to be used for the design of the mechanical components of the system will be SIEMENS NX, due to the experience of the designer with the previously mentioned software during his last job. SIEMENS NX is a powerful parametric mechanical design software, which allows to easily reshape the different parts involved in a mechanical design, through a complex system of relations between design features, and the use of constraints over them. This software is also capable to manage high complexity assemblies and the relation between them through constraints.

2.3 SENSOR CONTROLLER:

The sensor controller is at the same time divided in several subparts:

- Control box top
- Control box bottom
- Sensor box right
- Sensor box left
- Sensor glasses(right and left)
- Control PCB (which will be only briefly described regarding to the mechanical characteristics due to the fact that this part belongs also to the electronic design section)
- emitters PCB.
- receivers PCB.

(These two last parts, will also have a brief description for the same reasons mentioned for the case of the Control PCB).

Before the beginning of the description of the different parts, let's have a look to the figure 2.1 and 2.2, showing the container.

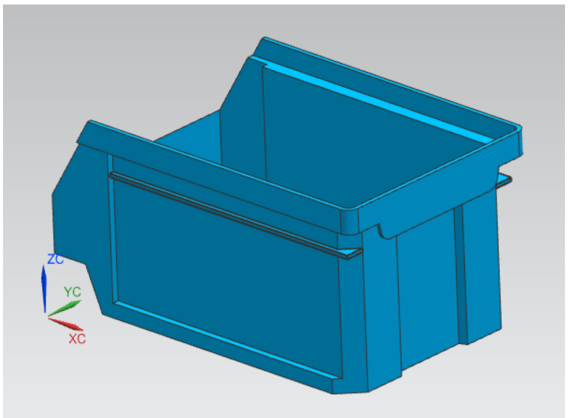


Figure 2.2

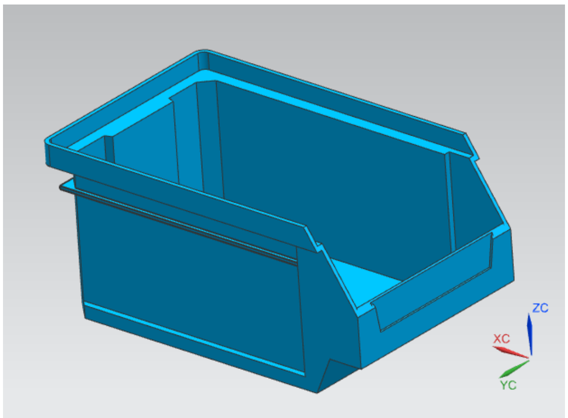


Figure 2.1

And a second picture containing the whole assembly:

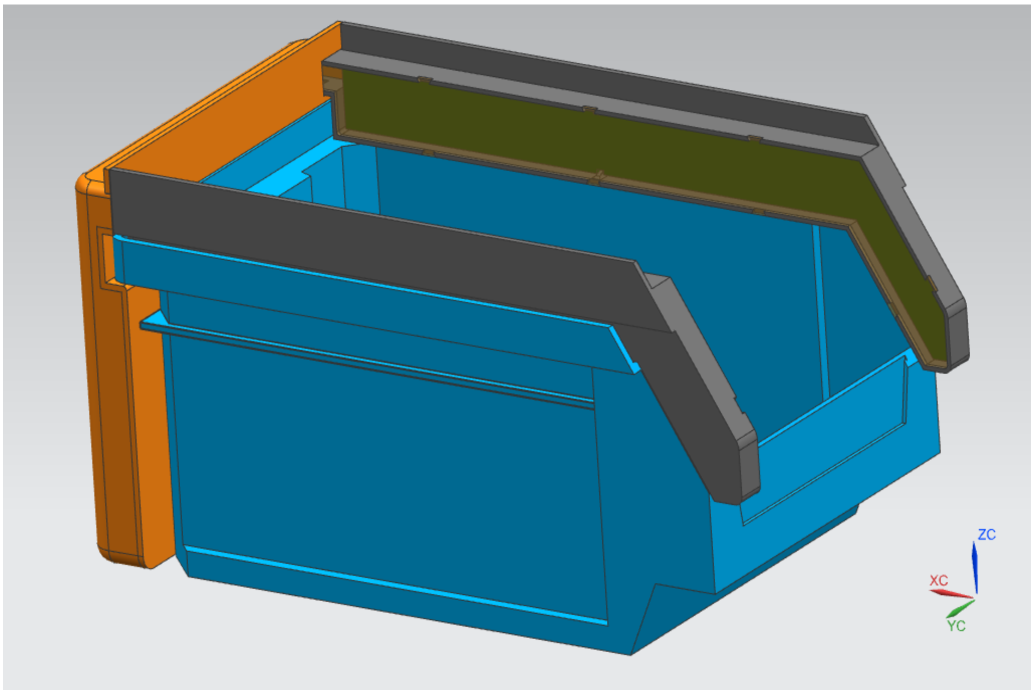


Figure 2.3: Container with the sensors and controller already assembled.

2.3.1 CONTROL BOX TOP

The Control Box Top part, will be the one which covers the electronic control circuitry, it will also have, as can be seen in figure 2.4, two hollows in which the connectors of the electronic circuitry will fit, which use will be to connect with the console, and to have easy access to debug/update the firmware of the sensor controller.

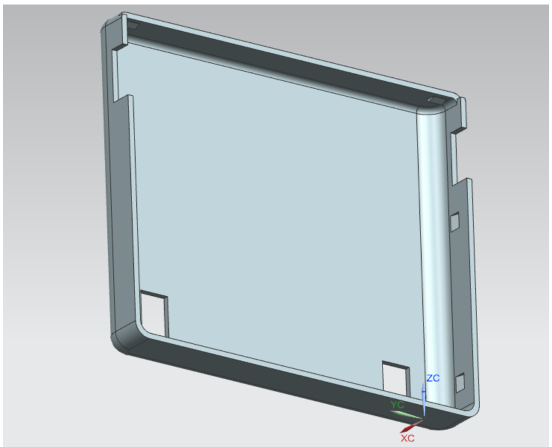


Figure 2.5: Control box top, inside.

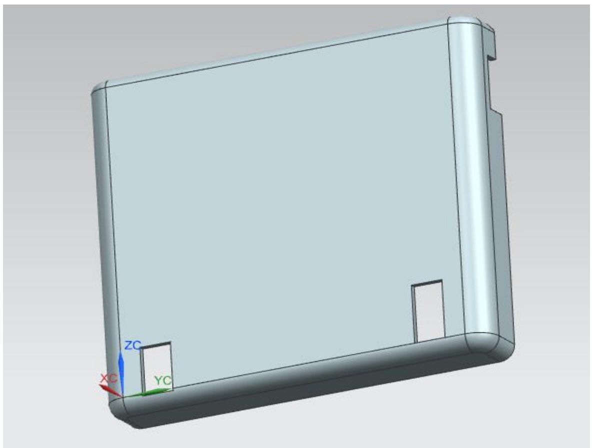


Figure 2.4: Control box top, outside.

On the other side is also possible to appreciate the cavities and outgoings that will be used for the fixation with the other parts comprising the sensor controller.(Figure 2.6)

The width of this part is determined by the size of the chosen connectors, trying to keep it as small as possible, not to disturb the form factor of the container.

The thickness of the material will be kept in 1.5 mm, which gives robustness and flexibility, without an excess of material use.

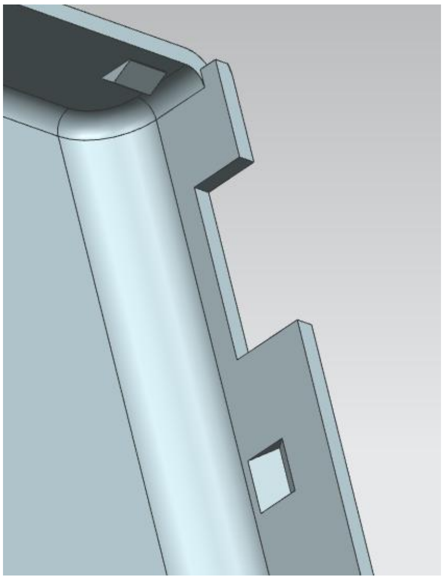


Figure 2.6 : Detail on control box.

2.3.2 CONTROL BOX BOTTOM

The Control Box Bottom part, will hold the PCB and is also the one which fixes it to the container, it contains a hollow to get fixed through the back flap of the container, and several holes to fix the PCB by means of screws, those laying inside the box, not disturbing the overall look of the cases, as can be seen in figure 2.7 also is possible to appreciate the profile of the case, which is adapted to the backside of the container.

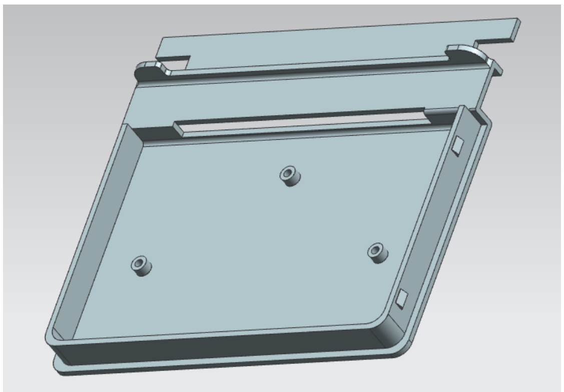


Figure 2.7: Control box bottom, inner view.

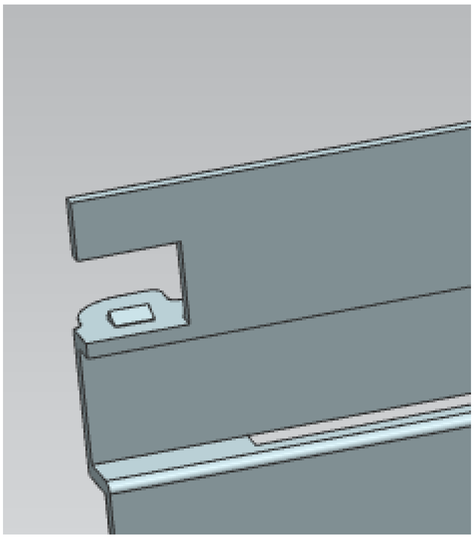


Figure 2.8 : Detail on control box bottom.

On the figure 2.8 is possible to see again the little outgoings which will be used to fix the control box to the sensor boxes. The square hollows on both sides will be used to insert them, and together with the Control Box Top, will give the right fixation.

For the same reasons previously mentioned, the overall thickness of this part is also kept to 1.5mm. The outgoings, could represent a problem in the simplicity of the design of a plastic injection mold, because they could be seen as generating undercuts, but they were designed with a size small enough that allows the parts to be sprout from the mold with the help of ejectors.

2.3.3 SENSOR BOX LEFT/RIGHT

In the case of the sensor boxes, the design of both is the same, but inverted through the x-axis. So we will describe them together. Pay attention to the figure 2.9 to notice their characteristics.

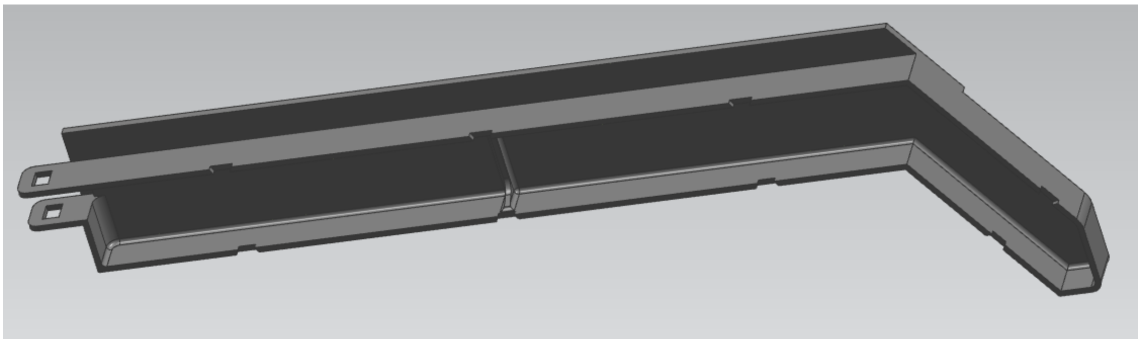


Figure 2.9: Sensor box, left side.

The interesting points about the design of this part are the following:

- The square on the left, to fix it to the Control Box Bottom and Top.
- The small keystone shaped cavities along all the part, used to fix the sensor glasses.
- The central pillar on the big cavity, which accomplishes a double function, avoid the part to get very deformed due to the injection molding process, and hold the sensor/receiver PCB.
- Finally, There is a flap on the top of the part, with similar characteristics as the one in the original container, with the finality of keeping the original functionality of the container being able to stack several boxes even when they have the sensor system installed.

In this case, the overall thickness of the part is a little lower (1 mm) due to the need to optimize the space, bound by the size of the PCB, which is determined by the size of the connectors for the wiring of the emitters/receivers.

2.3.4 SENSOR GLASS

The so-called sensor glass isn't really a glass, but a 1mm thickness sheet of acrylglass named with the reference 9C20, which is transparent to a wide range of the IR light spectrum, as is possible to notice in the figure 2.10.

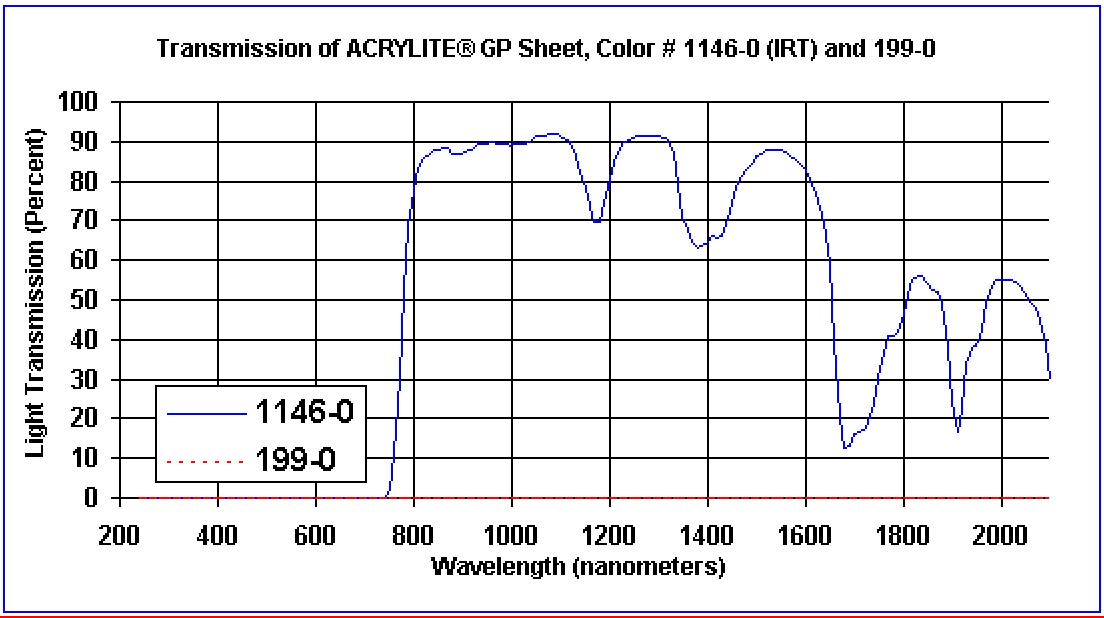


Figure 2.10: Light transmission of the IR glass against wavelength.

This part is designed to be completely flat as can be seen on figure 2.11 to avoid possible undesired reflections of the emitters, having also an added advantage for the manufacture. The process to manufacture this part is slicing with a laser cutter, from a big dimensions sheet. Is also possible to appreciate the keystone shaped outgoings, to fix it to the above mentioned Sensor Box.

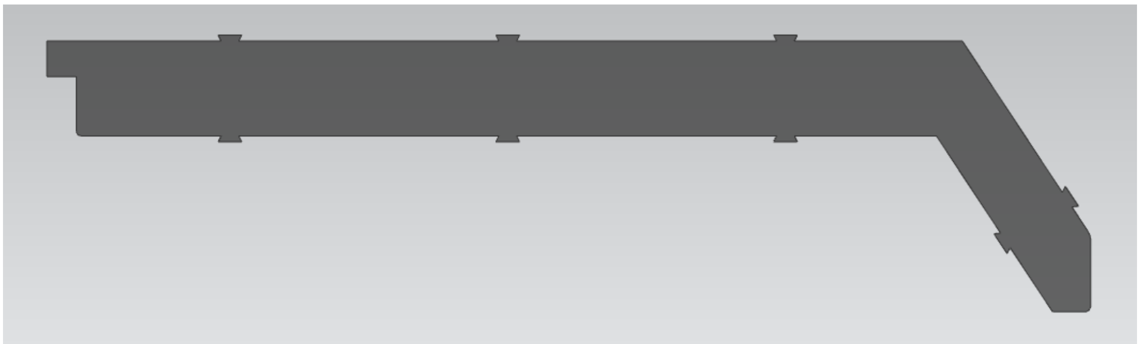


Figure 2.11: Sensor glass.

2.3.4 CONTROL PCB:

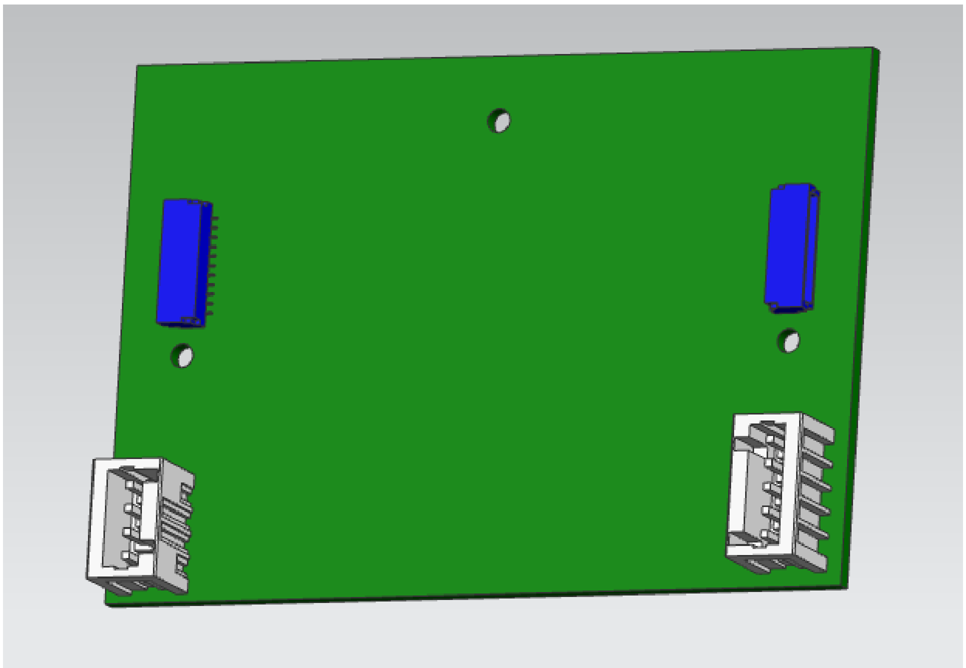


Figure 2.12: Control PCB.

The spots of interest in the Control PCB, besides the screwing holes used to fix the PCB to the SENSOR BOX BACK, are the connectors:

- The blue ones are JST-SM11SB to match the connectors needed on the Sensor PCB, still, those connectors don't contribute with any extra advantage to the PCB, in difference with the case of the sensor PCB , so it's possible that they will get replaced, for other kind of connectors.

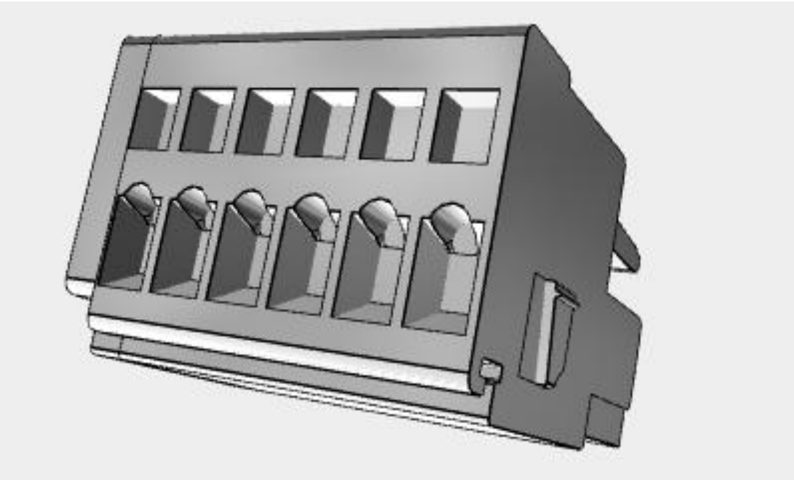


Figure 2.13: WAGO 733 series connector.

The white connectors are WAGO 733-334 and 733-335, fitting on those the plugs from the same manufactured, with the reference 733-104 and 733-105.

The main advantage of using this connector, is that they are 0.1

inch pitch, so is really easy to find other connectors which easily fit on them, also the advantage of being able to exchange easily the wires attached on the 733-104/105 (see figure 2.13).

2.3.5 SENSOR/RECEIVER PCB:

Those are the PCB's containing the emitters and the receivers themselves, the description of such devices is out of the scope of this chapter, so it will be explained later, when talking about the electronic design.

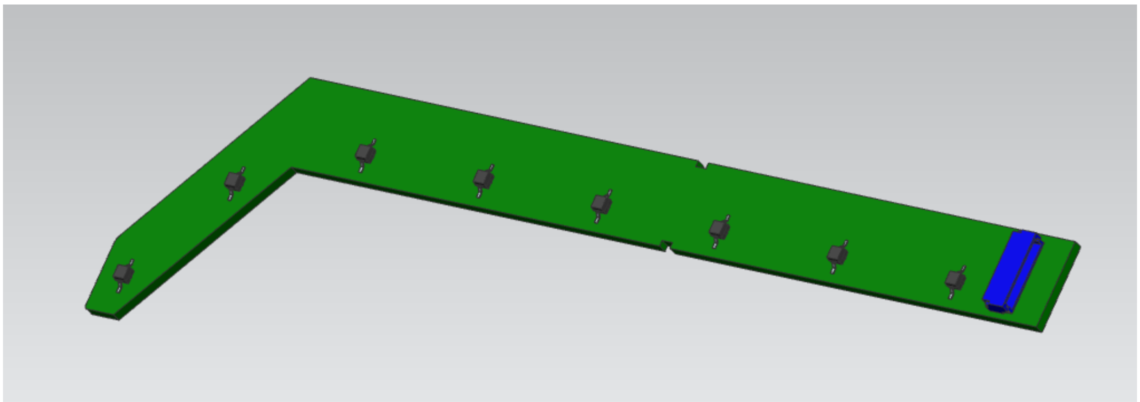


Figure 2.14 Emitter PCB.

Regarding to the mechanical design, the interesting aspects of the PCB are those:

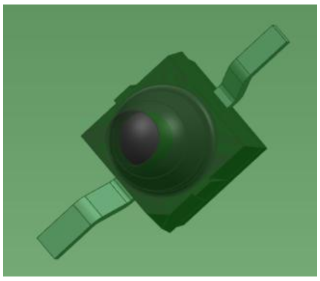


Figure 2.15 : Reverse Gullwing LED

-The hollows in the PCB for the fixation with the sensor box, the shape .

- The sensors, which are pointing through the PCB, using a reverse Gullwing package, quite rarely used, so besides the soldering pads of the sensors are on the side seen in figure 2.15 the sensors will be pointing through a hole on the PCB to the sensor receiver PCB.

- Pay attention also to the connector, which is the smallest form factor the writer could find to make it fit in such a small space. The connector is a JST-SM11SB, 11 contacts with 1 mm pitch.

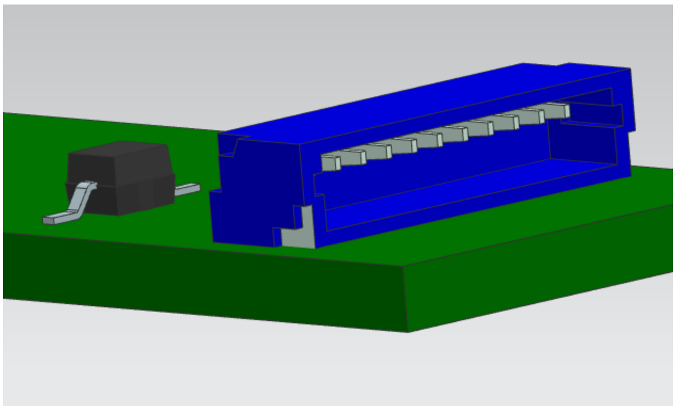


Figure 2.16: JST-SMB11 connector.

Important to note, the distance between the sensors, which will be always, 23 mm for the reasons explained in the section 2.3.6 due to the characteristics of the emitters and receivers.

2.3.6 POSITIONING OF THE SENSORS

As will be easy to appreciate at the drawings 2.7 and 2.8 (where the emitters and the receivers are shown), the distance between emitters is always 23 mm, same as the distance between receivers, so they're pointing to each other. The reason to use this distance is to try to avoid the beam of the adjacent emitters over any sensors which is not the one the emitter is pointing. Looking at the Datasheet of the VSMB2020, we can find the angle of half sensitivity being 12º, which means an effective beam angle of 24º, as can be seen in the figure 2.17.

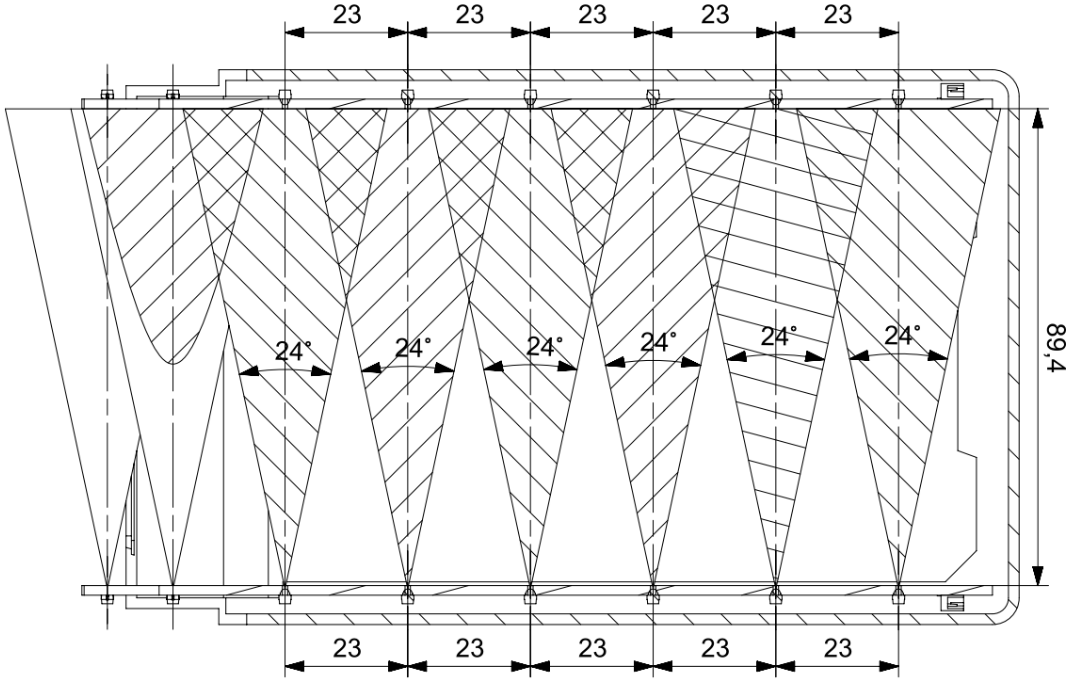


Figure 2.17 : Positioning of the emitters and receivers to avoid non-matched beam.

Anyways, after further experimentation, the designed realized that there are secondary beams pointing to the receivers, thing that could be used as a feature to improve the detection system <u>if it's properly managed through software.</u>

2.4 CONSOLE:

As mentioned before, holds all the electronics to interact with the device, the connectors for the boxes, but also the power supply and the supply switch.
Let's show the parts that compose the console and the design limitations.
The components of the console are:

- Box Front
- Box Back
- Box Top
- Box Bottom
- Console PCB, comprising all the components fixed to it.
- Locker

- Screen
- Encoder
- button
- power plug
- power switch
- buzzer
- relay

2.4.1 BOX FRONT AND BACK

The Box Front and the Box Back are the parts in which all the components with outer access will be attached, so in case of the front, it will contain holes for the locker, the screen, the encoder and the button. It will also have four holes in the corners, to fix it to the top and the bottom.

The back, will contain the holes for the power switch, the power plug, the connector for four sensor controllers and the chain connectivity, which will be described in more detail in the electronic design section. It also contains the same fixing holes as the front.

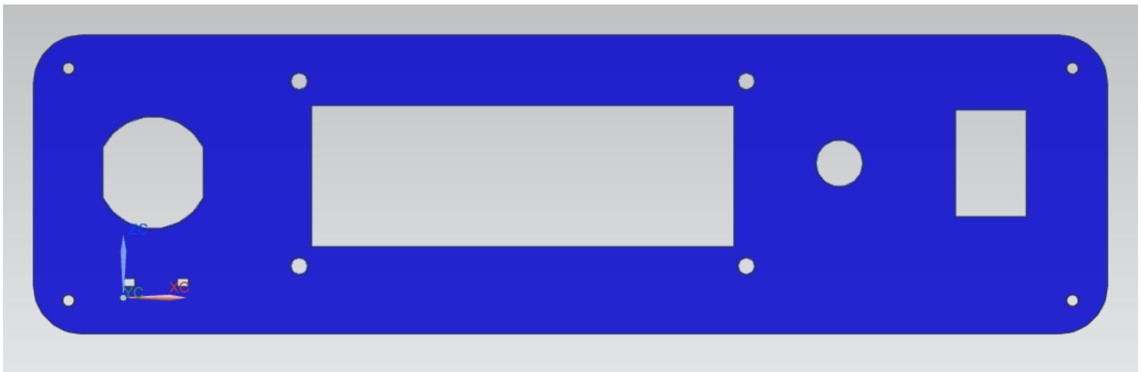


Figure 2.18: Console box front, frontal view.

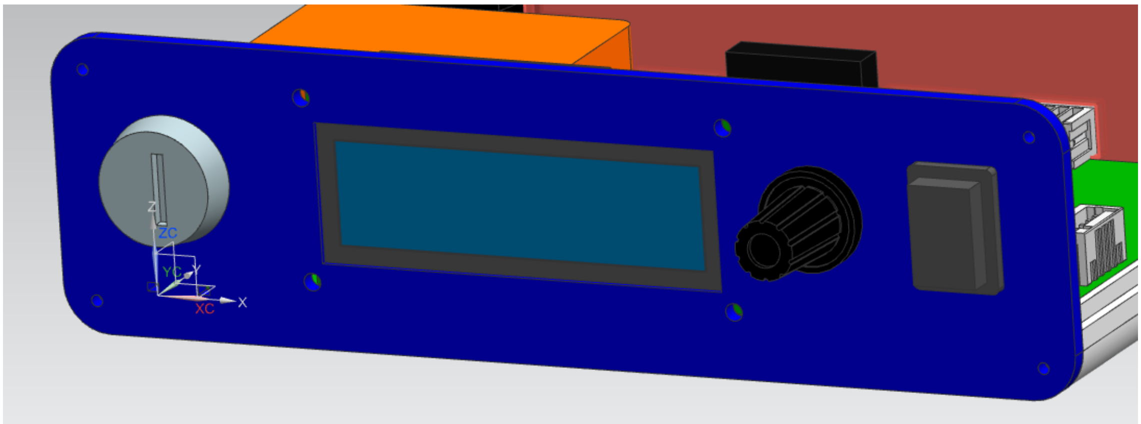


Figure 2.19: Console box front, with assembled parts.

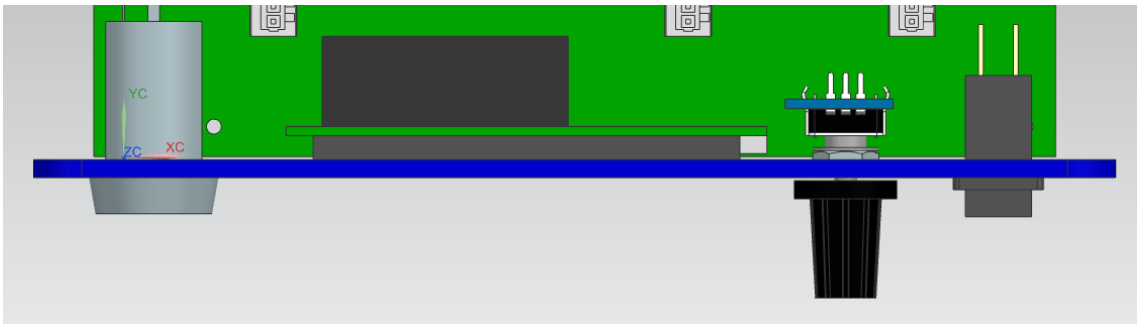


Figure 2.20: Console box front, top view, with assembled parts.

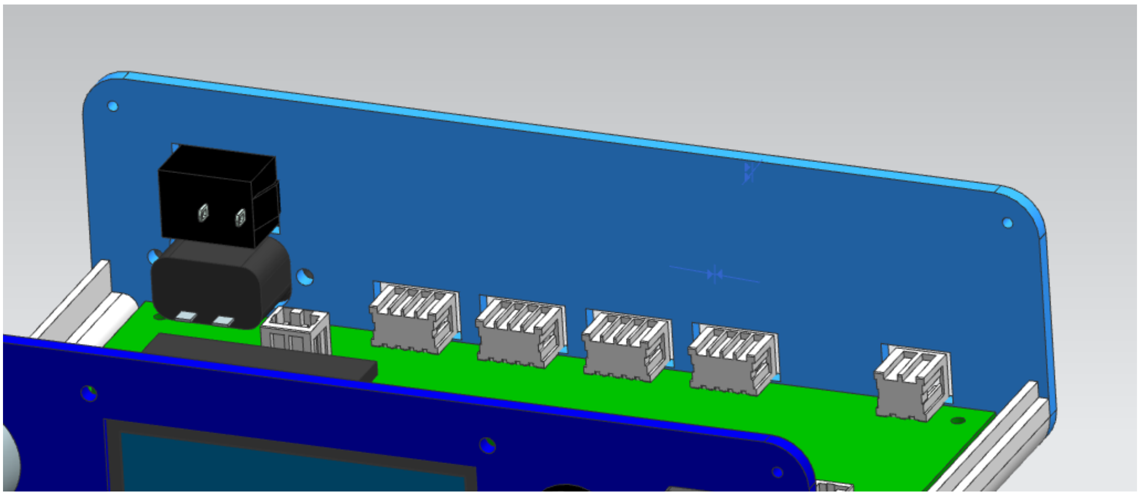


Figure 2.21: Console box back, inner view.

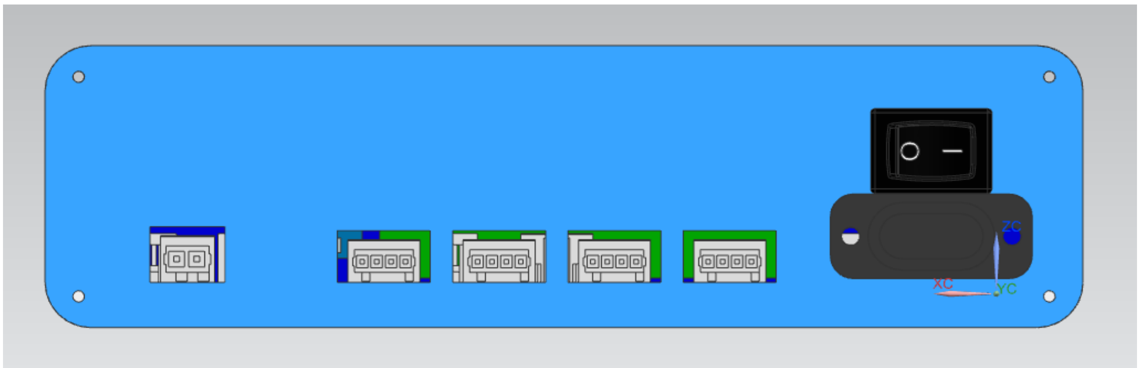


Figure 2.22 : Console box back, outer view.

Is important to note, in the first design phase, the connectors to the sensor controllers were in the front side, giving easier access to them, but after thinking deeply on the usability of the console, was decided to move them to the back side, so the wires are not interrupting the easy access to the button, encoder and screen, which will become the center of the interaction.

Both parts were designed using a flat surface, with the intention of manufacturing them with a sheet of 3-4 mm plexiglass or plywood through laser cutting process, inasmuch as the designer has access to such laser cutter for those materials, and is also a very easy and cheap manufacture method (due to the lack of need of a mold, unlike in casting processes).

2.4.2. BOX TOP AND BOTTOM

The top and the bottom part will have a similar geometry, they will fit on each other, housing all the console circuitry, and will be fixed through screws to the front and the back side.

The bottom side will contain four plugs to fix the PCB through screws, in the same way, the top side will have a couple of plugs to fix the buzzer.

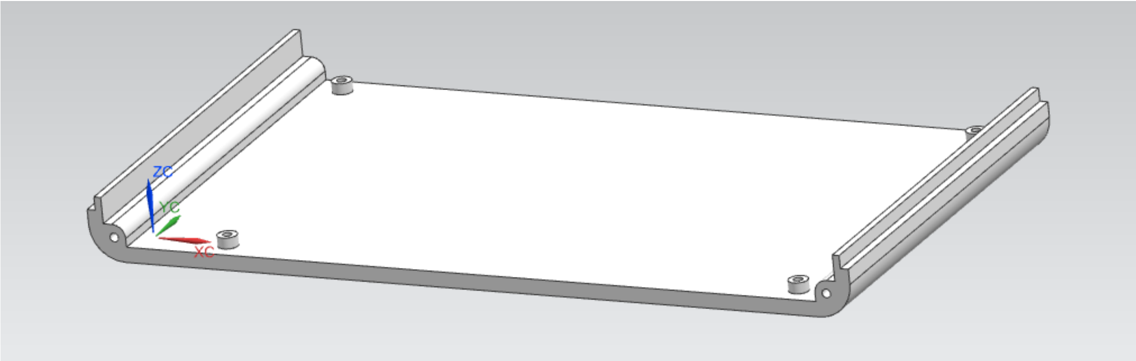


Figure 2.23: Console box bottom.

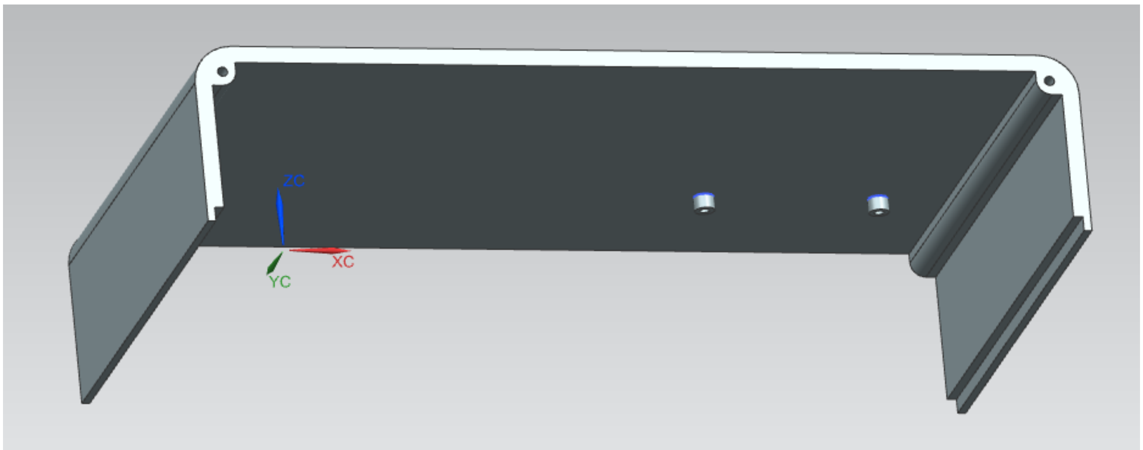


Figure 2.24: Console box top.

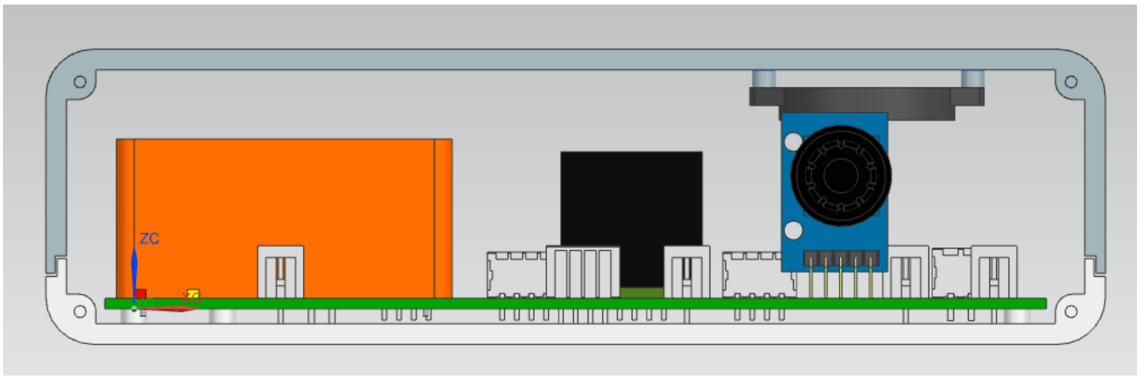


Figure 2.25: Top and bottom sides, including the PCB and the buzzer.

2.4.3 CONSOLE PCB

Regarding to the mechanical design, the main point of interest is the location of the connectors and the I/O devices. As much as can be directly attached to the PCB, as better, so it will give robustness and reliability, but the fact is that is much more important to give the right position to the I/O devices, so it becomes easy to interact with the system.

As can be seen in figure 2.25, the rear connectors, used to connect the console to the sensor controllers, and the chain connector, used to connect to other machines part of the assembly process, are the only components on the back side which are to be used outside the housing of the console.

On the front side, the encoder is the only part which protrudes the console case.

All the rest of the components needed to be air wired, and connected to the PCB.

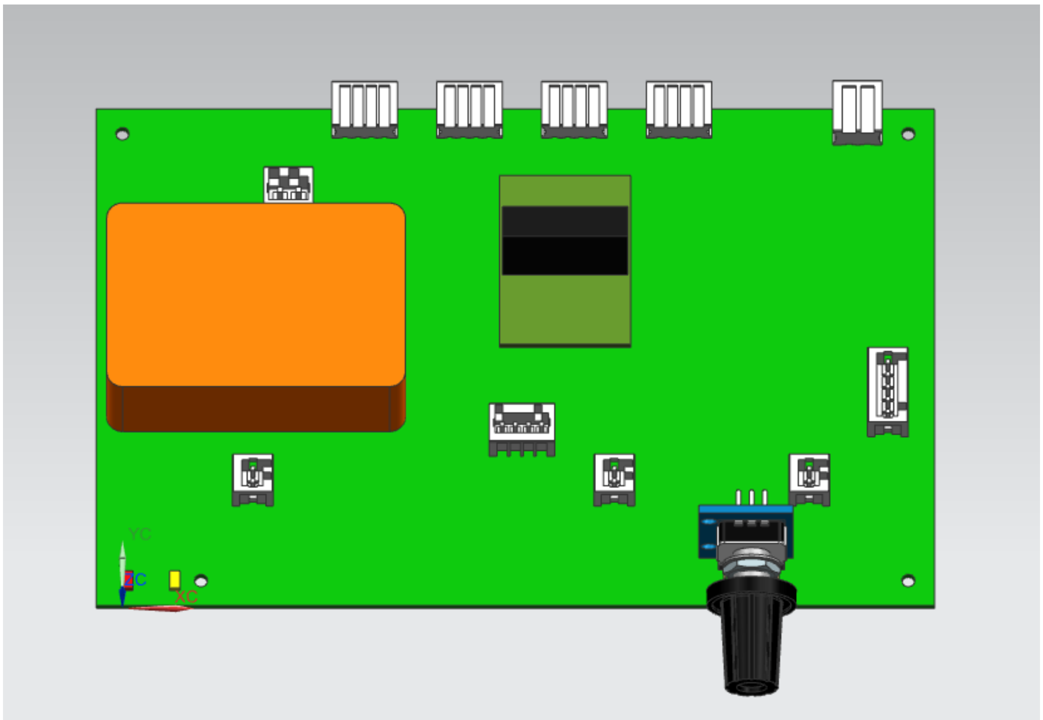


Figure 2.26: Console PCB

In the initial stage of the design, the connectors to the sensor controllers, were on the front side, but once the wiring is connected, makes uncomfortable to work with the I/O devices, and also implied to make the PCB much longer, the same way as the housing.

All the rest of the connectors, were placed to serve internal device connection, like the screen or the locker.

The size of the power supply (orange on figure 2.25) was in the initial stage of the design, the most limiting factor for the size of the console.

2.4.4. OTHER COMPONENTS:

Locker:

The locker(figure 2.27), is a standard SPST key switch, with a 19.5 mm mounting hole, which can be provided by several manufacturers. There isn't any

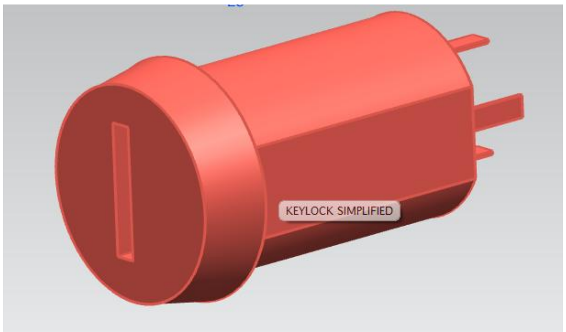


Figure 2.27: Locker, keyswitch.

datasheet for this part, so it will be replaced in case of a further versions, to ensure the technical characteristics.

Placed on the front panel to give easy access to the supervisors to change the options.

Screen:

This screen is a 1602 LCD, widely used along consumer electronics devices, which can be manufactured in very different sizes and shapes, but most of them have the same dimensions, so they're compatible with each other, the dimensions are shown in figure 2.28 Placed at the center of the front side to make easy for the users to read the displayed messages.

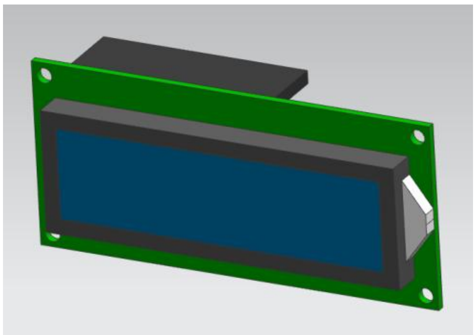


Figure 2.28: 1602 LCD screen.

Encoder and button:

The encoder is a ready to use KEYES module, easy to find on EBAY, probably based on a **TYCO DP12SV** encoder. There are lots of different encoder modules with the same dimensions, so it is easy to find other models which fit the same dimensions (figure 2.29).

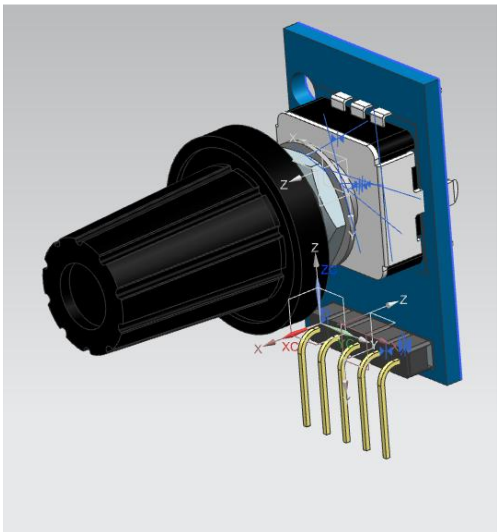


Figure 2.29: Keyes encoder module.

The button is a **1662.0101** switch from **MARQUARDT**, the dimensions of this button are a de facto standard, so it's possible to find lots of other buttons with the same dimensions (figure 2.30).

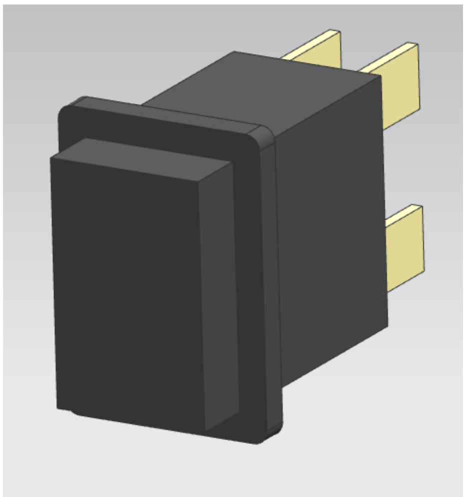


Figure 2.30: Button.

Both input devices are placed to interact with the console, located on the right side, taking in consideration most of the population is right handed, should be easier to use (besides the designer is left handed).

power plug and power switch:

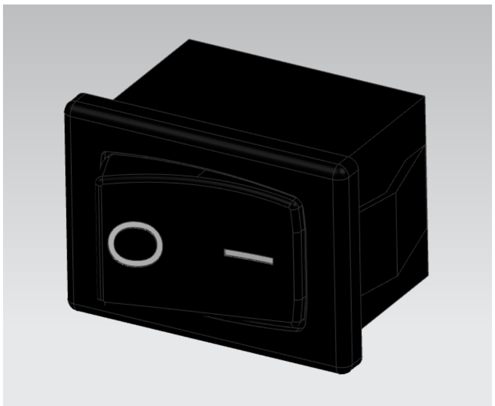


Figure 2.31: Rocker switch.

The power switch is a so called rocker switch, there are several different models with the same specification, but in this case, the used one will be the **MARQUARDT 1801.1121**.

The power plug is a **C7 IEC standard female power plug**. There are lots of different manufacturers which provide this kind of connector.

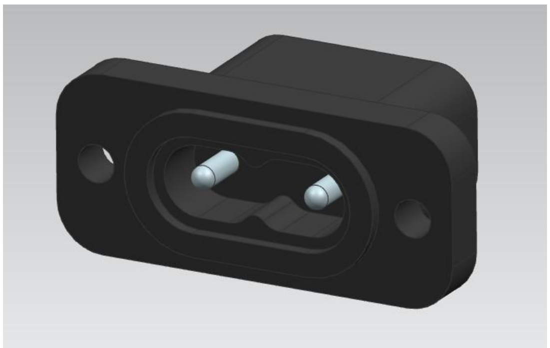


Figure 2.32: C7 IEC power plug.

Keeping the switch close to the plug, it gets clear is to switch off the machine, on the back side.

Buzzer:

The used buzzer (Figure 2.33), is one of the most common models used by the Arduino community, which most probably will be a **PKM34EW-1101C/1201C** from the manufacturer **MURATA .**
This buzzer emits sound when some operations are performed, if fixed to the housing, will transmit better the vibrations.

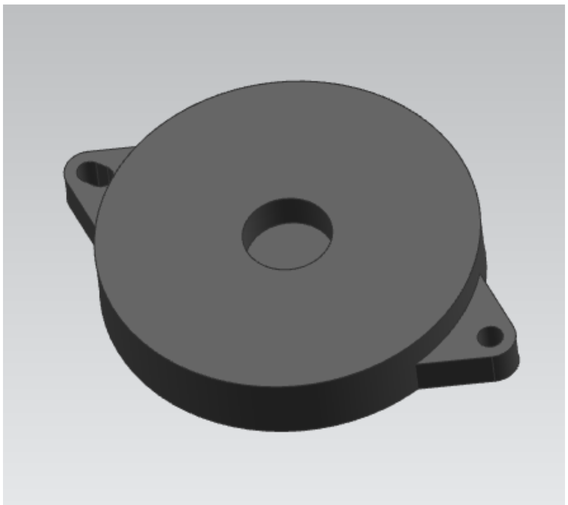


Figure 2.33: Buzzer

Relay:

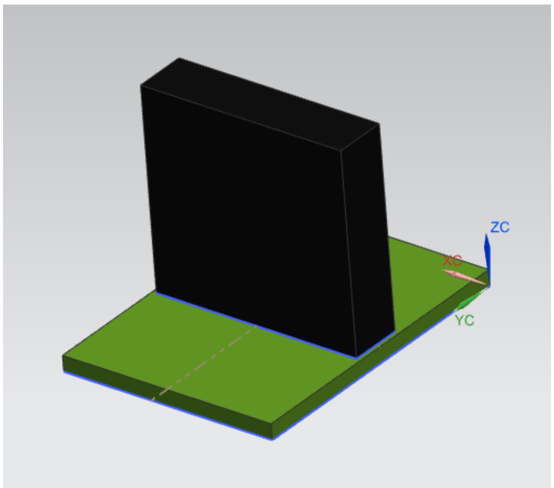


Figure 2.34: Relay

To connect to other devices related with the assembly process. This device doesn't have any kind of fixation because it could easily change the shape and dimensions of the module, and at the moment of the beginning of the manufacturing from the PCB's this component wasn't clearly determined. As can be seen in figure 2.34, this is only a simplified indicative

model.

3. ELECTRONIC DESIGN

3.1 INTRODUCTION:

The electronic design part consists mostly in the design of the PCB and the choice of the right electronic components for meeting the required characteristics given in the specification, and given by the relations of the components between themselves, besides this text is structured in a very linear way, this far away from a real design stage, which is mostly iterative, in which the designer conveniently changes some to get adapted to other. Also is the same with the relation between the mechanical design and the electronics design.

So this is only the result of this iterative process.

3.2 SOFTWARE:

The software used for the electronic design during this project, will be EAGLE. EAGLE is flexible expandable and scriptable electronic design application, with schematic capture editor, PCB layout editor, auto-router and CAM and BOM tools. Besides is not a very intuitive software, once a designer gets used to it, makes the design fast and flexible.

The designer of this project will use the schematic and the layout editor for the development of the electronic circuitry. Besides there are some scripts which allow eagle to use simulation, they are quite complicated tools, not fully integrated in the software, and most of the time the simulations need components to be replaced, which makes simulation unworthy.

The main advantage of the EAGLE software is the existence of free versions for hobbyists and students downloadable directly from CADSOFT.

3.3 PREVIOUS CALCULATIONS

Given by the specification there will be a maximum of 4 boxes, each of them will have the same power consumption. The starting point will be a power supply of maximum 10W, to try to design a non excessive consuming device. In case is not possible to meet the specification using only 10W, the power supply will be resized.

So a safety margin for the power supply will be used, using only the 70% of the rated value, which means maximum power consumption of the system 7W.

4 boxes with same power draw, we assign a maximum power draw per box to 1 W.

From the calculations related to the beam and the number of sensors needed to properly detect a hand inside the container, we will get a total 8 emitters and 8 receivers, which power draw was estimated to be a maximum of 0.5W for the emitters, 100mW for the receivers.

The power consumption of the PIC is estimated to be 0.15W, through the measurement of the power draw of other similar designs.

The control PCB also contains a couple of LED's used to check the correct operation of the device, consuming 0.01W, almost negligible power draw.

Also the pull up resistors used for a possible I2C communication have a non-relevant power draw.

Considering an efficiency on the power regulator which supplies the whole control board of a 90% (this device is rated with a maximum efficiency of 95% on its sweet spot).

This means, in the worst case, we will be under the maximum assigned power consumption, which is 1W per box.

Using 3.3 volts, the power draw will be considerably reduced, but this could cause problems with the communication with the console, so this point should be revisited after the device testing.

IMPORTANT NOTE:

Those were only rough calculations to have a first impression of the power draws needed by the different parts of the system, to dimension the power supply and the regulator, but the final design may differ.

3.4 SENSOR CONTROLLER

The sensor controller as its name says, will be in charge of controlling the sensors attached to every container, besides all parts of the system together can be seen as a whole circuit, it will be divided in three different parts, regarding to the division in different PCB's that has been done in the system for mechanical reasons(to get properly adapted to the container) and also thinking in the possibility of replacing some of the sensing modules for others with different characteristics. Besides, as said there will be three differentiated parts, also will be added a possible variation to one of them.

So the sensor controller will be divided in the following:

- Controller board:
Containing the control logic, the power regulation, and a power stage for the LED driving.

- Emitter board:
Containing the IR LED's used as emitters.

- Receiver board:
Having two different alternatives. First case, using phototransistors, second case using IR receivers, the justification for this alternatives will be explained in the corresponding section.

3.4.1 CONTROLLER BOARD:

Let us get started having a look to the final schematic design to point out the used components:

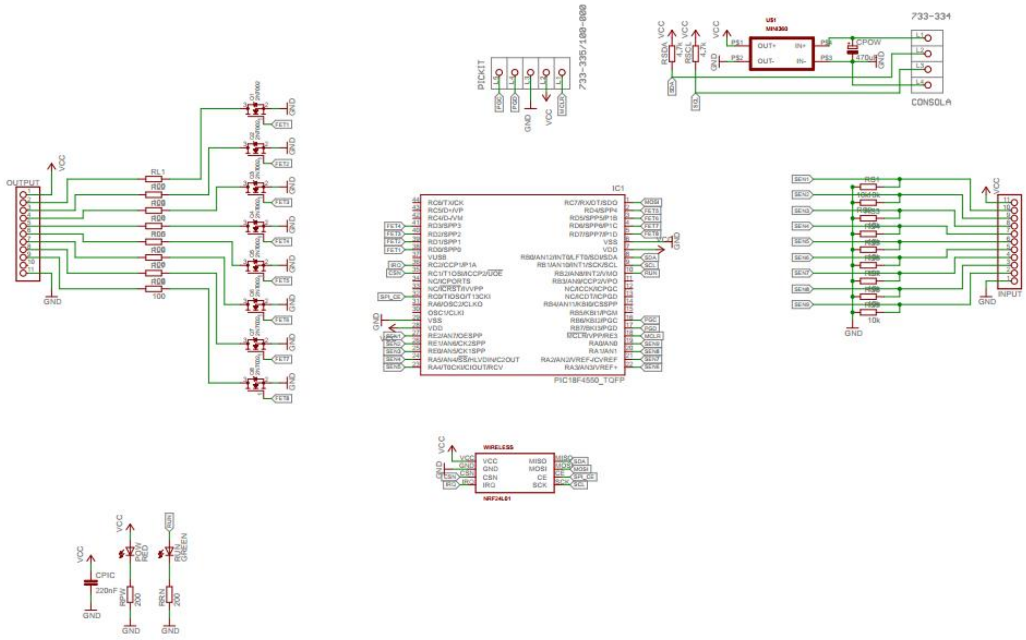


Figure 3.1: Console Schematic.

As can be seen in the figure 3.1 The circuit contains:

- The microcontroller, at the center.
- A connector to the in-circuit programmer on the center top.
- The connector to the IR LED's, the current limiting resistors for the LED's and the transistors needed to drive them to a higher current than the pins of the microcontroller can supply, on the left side.
- Another connector for the receivers with pull down resistors for each sensor, on the left side.
- The power and the run LED's, with its current limiting resistors, on the left bottom.
- A filter capacitor for the power of the microcontroller, also on the left bottom.
- The pull up resistors for the communication with the console, the power regulator, a filter capacitor for the power regulator, and the connector to the console.

The microcontroller

As will be described in the further software sections, the device is a 8 bit microcontroller PIC18f4550 from the company Microchip, here you can find listed some of its characteristics:

Universal Serial Bus Features:

- USB V2.0 Compliant
- Low Speed (1.5 Mb/s) and Full Speed (12 Mb/s)
- Supports Control, Interrupt, Isochronous and Bulk Transfers
- Supports up to 32 Endpoints (16 bidirectional)
- 1-Kbyte Dual Access RAM for USB
- On-Chip USB Transceiver with On-Chip Voltage Regulator
- Interface for Off-Chip USB Transceiver
- Streaming Parallel Port (SPP) for USB streaming transfers (40/44-pin devices only)

Power-Managed Modes:

- Run: CPU on, peripherals on
- Idle: CPU off, peripherals on
- Sleep: CPU off, peripherals off
- Idle mode currents down to 5.8 µA typical
- Sleep mode currents down to 0.1 µA typical
- Timer1 Oscillator: 1.1 µA typical, 32 kHz, 2V
- Watchdog Timer: 2.1 µA typical
- Two-Speed Oscillator Start-up

Flexible Oscillator Structure:

- Four Crystal modes, including High Precision PLL for USB
- Two External Clock modes, up to 48 MHz
- Internal Oscillator Block:
  - 8 user-selectable frequencies, from 31 kHz to 8 MHz
  - User-tunable to compensate for frequency drift
- Secondary Oscillator using Timer1 @ 32 kHz
- Dual Oscillator options allow microcontroller and USB module to run at different clock speeds
- Fail-Safe Clock Monitor:
  - Allows for safe shutdown if any clock stops

Peripheral Highlights:

- High-Current Sink/Source: 25 mA/25 mA
- Three External Interrupts
- Four Timer modules (Timer0 to Timer3)
- Up to 2 Capture/Compare/PWM (CCP) modules:
  - Capture is 16-bit, max. resolution 5.2 ns ($T_{CY}/16$)
  - Compare is 16-bit, max. resolution 83.3 ns (T_{CY})
  - PWM output: PWM resolution is 1 to 10-bit
- Enhanced Capture/Compare/PWM (ECCP) module:
  - Multiple output modes
  - Selectable polarity
  - Programmable dead time
  - Auto-shutdown and auto-restart
- Enhanced USART module:
  - LIN bus support
- Master Synchronous Serial Port (MSSP) module supporting 3-wire SPI (all 4 modes) and I^2C™ Master and Slave modes
- 10-bit, up to 13-channel Analog-to-Digital Converter module (A/D) with Programmable Acquisition Time
- Dual Analog Comparators with Input Multiplexing

Special Microcontroller Features:

- C Compiler Optimized Architecture with optional Extended Instruction Set
- 100,000 Erase/Write Cycle Enhanced Flash Program Memory typical
- 1,000,000 Erase/Write Cycle Data EEPROM Memory typical
- Flash/Data EEPROM Retention: > 40 years
- Self-Programmable under Software Control
- Priority Levels for Interrupts
- 8 x 8 Single-Cycle Hardware Multiplier
- Extended Watchdog Timer (WDT):
  - Programmable period from 41 ms to 131s
- Programmable Code Protection
- Single-Supply 5V In-Circuit Serial Programming™ (ICSP™) via two pins
- In-Circuit Debug (ICD) via two pins
- Optional dedicated ICD/ICSP port (44-pin devices only)
- Wide Operating Voltage Range (2.0V to 5.5V)

Figure 3.2: PIC18F4550 highlights.

Device	Program Memory		Data Memory		I/O	10-Bit A/D (ch)	CCP/ECCP (PWM)	SPP	MSSP		EAUSART	Comparators	Timers 8/16-Bit
	Flash (bytes)	# Single-Word Instructions	SRAM (bytes)	EEPROM (bytes)					SPI	Master I^2C™			
PIC18F2455	24K	12288	2048	256	24	10	2/0	No	Y	Y	1	2	1/3
PIC18F2550	32K	16384	2048	256	24	10	2/0	No	Y	Y	1	2	1/3
PIC18F4455	24K	12288	2048	256	35	13	1/1	Yes	Y	Y	1	2	1/3
PIC18F4550	32K	16384	2048	256	35	13	1/1	Yes	Y	Y	1	2	1/3

Figure 3.3: PIC18f4550 features.

So as can be seen in the figure 3.2 the 18f4550 has 35 I/O pins, from which we will need:

-8 pins for the activation of the IR LED used as emitters.

-8 pins for the sensing of the receivers.

-2 pins for the communication with the console.

-1 pin for the "run" LED, which will blink while the device is active.

There will be the need of using other IO ports which have a multiplexed functionality, to use through them, the in-circuit programmer. Those pins need to be necessarily the pins 16,17 and 18, as can be seen in figure 3.3 which will not be available as IO.

Also the pins assigned to the communication with the console are fixed, to be coincident with the I2C port of the microcontroller, regarding to a possible future modification to use all the controllers unified in a single I2C bus.

Also can be seen the connection of some pins to a device called wireless. This device is an NRF24L01 wireless communication module, which will not be described further, because is a future modification out of the scope of this project, so it only be again commented in the modifications section.

The pins where to connect the IR LED's and the photo-sensors, were chosen to be adjacent and easy to route regarding the disposition of the elements in the PCB, as can be seen in the figure 3.4.

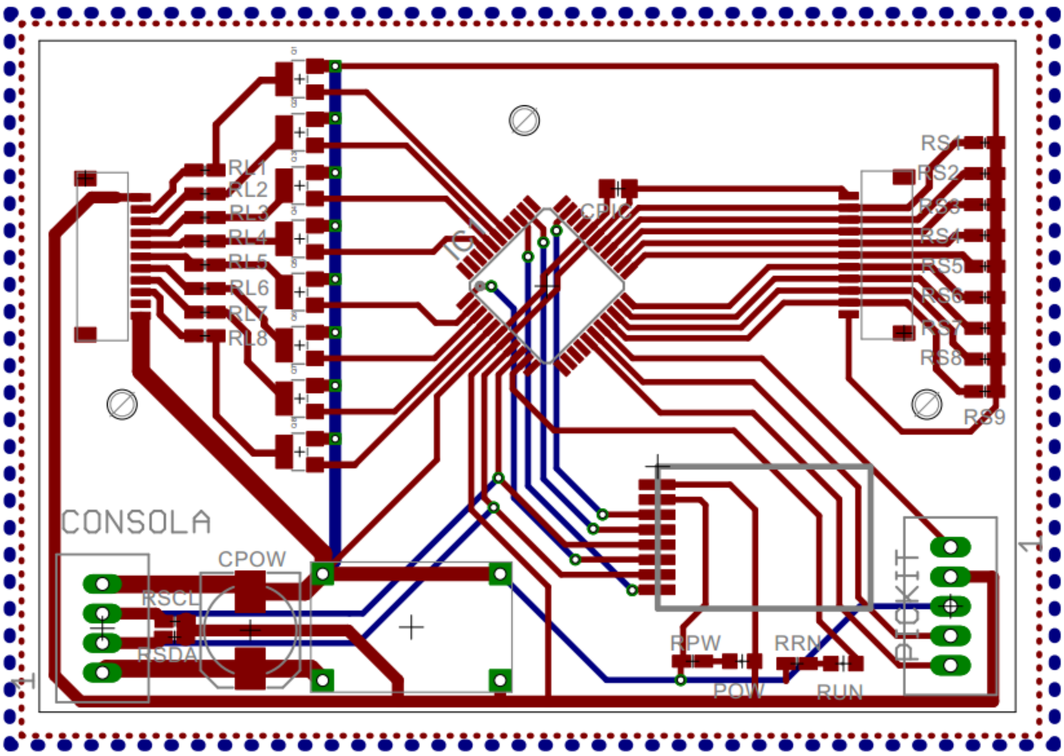


Figure 3.4 : Controller PCB.

Once the IR LED's and the sensors were correctly assigned to pins, then the rest of the pins were chosen, so the final allocation of the pins became as seen in the schematic.

The connector to the in-circuit debugger:

Contains five pins, according to the connectors that need to be done with the devices pickit2 or pickit3 those pins are power, ground programming clock, programming data, and master reset, to set the device in the programming mode.

The connector to the IR LED's

Already described and justified in the mechanical design section left to say that it contains 11 pins besides it needs only 10, to match the connector used on the side of the sensors.

The current limiting resistors for the IR LED's:

As their name explains are used to limit the maximum current through the LED's to its maximum value, which is 100mA, its value needs to be adjusted depending on the final set value of the power regulator, which could be 5 or 3.3 V, but the calculations will be done taking in consideration the worst case, 5Volt.

Those resistors will never dissipate more than 0.25W, so it's possible to use common SMD resistors.

The transistors, which will be of the type 2N7002, MOSFET topology transistors with this characteristics:

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{DS}	drain-source voltage	25 °C ≤ T_j ≤ 150 °C	-	-	60	V
I_D	drain current	V_{GS} = 10 V; T_{sp} = 25 °C; see Figure 1; see Figure 3	-	-	300	mA
P_{tot}	total power dissipation	T_{sp} = 25 °C; see Figure 2	-	-	0.83	W
Static characteristics						
R_{DSon}	drain-source on-state resistance	V_{GS} = 10 V; I_D = 500 mA; T_j = 25 °C; see Figure 6; see Figure 8	-	2.8	5	Ω

Figure 3.5: 2n7002 characteristics.

The reason to choose those transistors is they are widely available, matched switching speed for the application, power dissipation matching the application, not excessive on resistance, no fixed voltage drop in the junction (in contraposition with the BJT topology) and good price.

A capacitor to absorb possible voltage spikes that can generate unexpected behavior in the microcontroller(more information about this can be found on the microcontroller datasheet).

Connector for the receivers:

Same as in the case of the emitters (IR LED's), will connect to the receivers PCB, there's also an extra pin which is connected to an analog pin, just in case it's needed in future revisions.

Pull down resistors:

The pull down resistors, are set to be used with the phototransistors, and the system is thought to use them as switches, which means, its value must be taken from the equation:

Vcc> R * Ia (being Ia, the value of the light current, and R the value of the pull down).
This gives a value of:
R > 5V / 6 mA , R > 866 Ohm.

Anyway, this is only an indicative value, to use as start point for the test phase.

In the case of the modulated photoreceivers , as it will be explained in the section 3.6, there will be no need of those pull down resistors.

Power and run LED's:

If the system is powered on, the power LED, on this case white, will light up, if the microcontroller is also active, the blue run LED will blink.
The maximum allowed current through the LED's is 20 mA (extracted from seller's information) but taking in consideration there's no need to use the maximum brightness but to optimize the power consumption, the maximum current will be set to 4mA. so the resistors value will be:

Rlim = (Vcc - Vak)/ Imax
Rlim = (5- 3.2)/4mA
Rlim = 450 Ohm.

The chosen value will be the closest standard resistor value, 470 Ohm.
And the power consumption will be:

P = V*I

P = 5 * 4mA

P = 0.02W

Capacitor for the power of the microcontroller:

This capacitor is used to avoid high frequency ripple on the power of the microcontroller, to avoid parasitic resets holding the power stable. The recommended taken the reference of similar designs with a 18F4550 is 150 pF, but similar values will also work properly.

Pull up resistors for the I2C communication:

Those pull up resistors are placed to ensure the voltage reference on the communication pins between the controller and the console, considering a possible future modification to communicate both devices through the I2C protocol, two 4.7 KOhm resistors will be used, which is a commonly used value for the I2C, taking in consideration the I2C bus will be used only in low speed mode.

Power regulator:

The voltage supplied by the console is 12 Volt, to transmit more power with less loses through the wires which connect the console and the controller, but the voltage needed for the controller circuitry is from 3.3 to 5 Volt, so there's a need for a step down voltage regulator.

In this case, the voltage regulator will be a **MINI 360 step down switching regulator**, which is able to convert a voltage up to 23 Volts to a lower voltage, as low as 1 Volt, so it will be able to deliver both 3.3 and 5 Volts to the controller circuitry, just setting up the right value with the potentiometer included on the regulator. This circuit also shields the partially the possible voltage drops on the console to affect the controller circuitry.

(**IMPORTANT NOTE**: the regulator is set to its maximum value by default, so it MUST be tested and calibrated before soldering on the PCB or it may cause damage to the circuit).

Filter capacitor for the power regulator:

Used to hold the voltage stable on the controller side , in case of abrupt changes on the power consumption.

3.5 CONSOLE

Let us proceed with the console in the same way done with the controller, starting with the schematic, to show the different parts of the design.

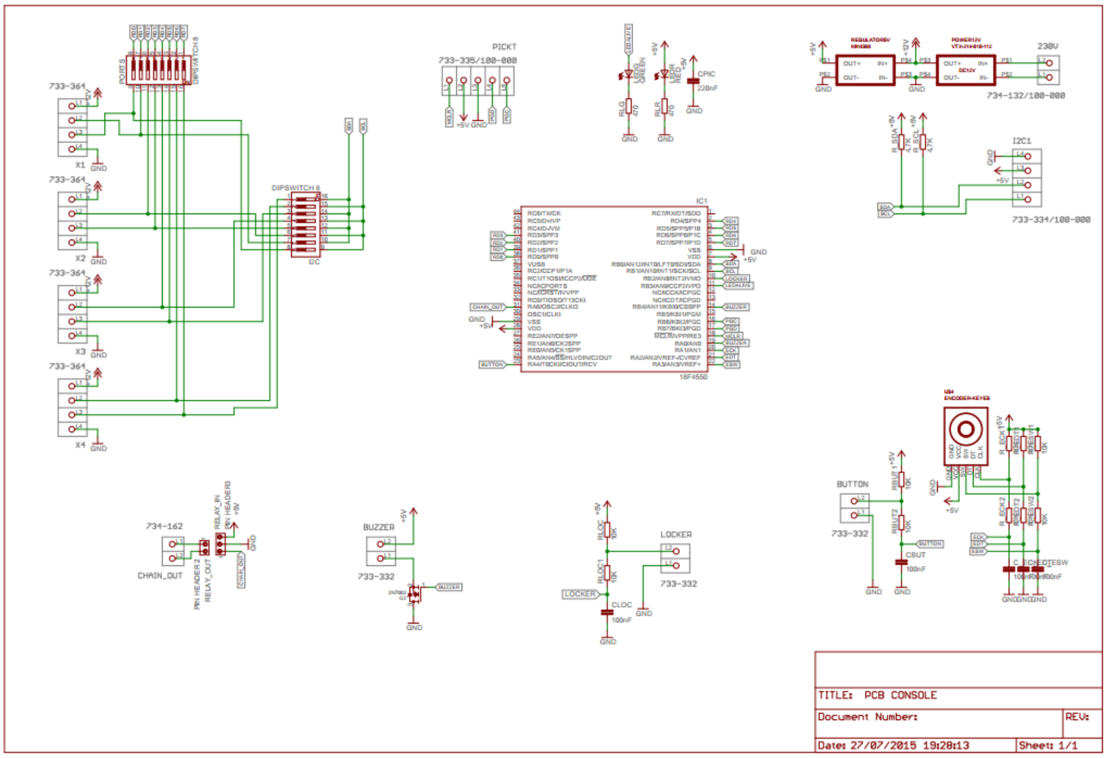


Figure 3.6: Console Schematic.

As can be seen in the figure 3.6 The circuit contains:

- The microcontroller, at the center.

- A connector to the in-circuit programmer, the power and the run LED's, with its current limiting resistors, with the recommended capacitor for the microcontroller power supply on the center top.
- On the left side, can be seen the connections to the four controllers, and also some switches, which will be used to reconnect the pins of the boxes to the I2C port, feature that could be used in future versions.
- At the right side on the top, can be seen the power supply, and a voltage regulator, plus the connector to the power plug.
- Below those, can be found the I2C port connection, used for the communication with the 1602 LCD.
- At the bottom, on the left side there are the connections used for the external switch, used to connect to other devices of the manufacturing process, from here and so on called "chain out."
- Moving to the right, we find the connections to the buzzer, which will be connected through a transistor, just in case there's a need to change the chosen buzzer for a more powerful one.
- Moving again to the right, we find the connection to the button.
- Finally on the right side at the bottom, the encoder and its additional circuitry can be seen.

The microcontroller:

The microcontroller of the console is the same as in the controller board, and its features are the same as described in section 3.3 (sensor controller).
The pins for the different devices attached to the microcontroller, were chosen to get a good distribution on the PCB, unless those that needed to be connected to specific pins, like the I2C port pins, and the Pickit In-Circuit-Programmer.

Connectors for the controllers:

They will be WAGO 733-334, as described in the section 2.3.4, Control PCB.
Each of those connectors consisting in 4 pins will be have the first and the last pin connected to the 12VDC power rail, and to ground respectively, whereas the other pins will be for the communication between the console and the controllers.

DIP switches:

Those are 8 contact 0.1 inch switches which will be used to conmute the functionality between dedicated ports to I2C bus for the controller boxes. While all of the switches of one package are on, all the switches on the other package must be off.

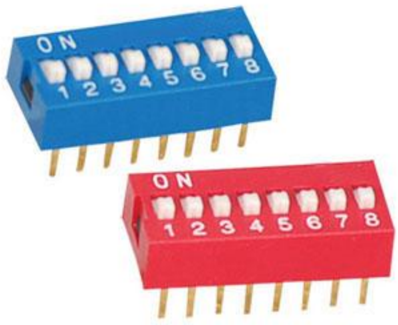


Figure 3.7: DIP switches.

Power supply:

The power supply will be a **VIGORTRONIX 214-010-112** which will convert the 230VAC from the net in 12VDC used to deliver the power to the sensors, which will be afterwards converted in 5 VDC to power the circuitry of the console.

I2C Port and 1602 LCD:

Through this connector attached to the I2C port of the microcontroller, which will also be a WAGO 733 series connector, the console circuitry will connect to the 1602 LCD, used to display information to the users. The LCD has an external circuitry attached to it, allowing to communicate by means of I2C protocol. The drivers for this device, were written for another project by the designer of this project.

Switch and encoder:

Used as input devices from the user, they have some extra external circuitry to perform a **HARDWARE DEBOUNCING** to avoid multiple detections due to the mechanical parts contained in the button and in the encoder.

The encoder is a **QUADRATURE DOUBLE STEP** rotary encoder. In the figures 3.8 and 3.9, can be seen the signal generated for this encoder while rotating clockwise and anti-clockwise.

Figure 3.8: Encoder turning counter-clockwise, two steps.

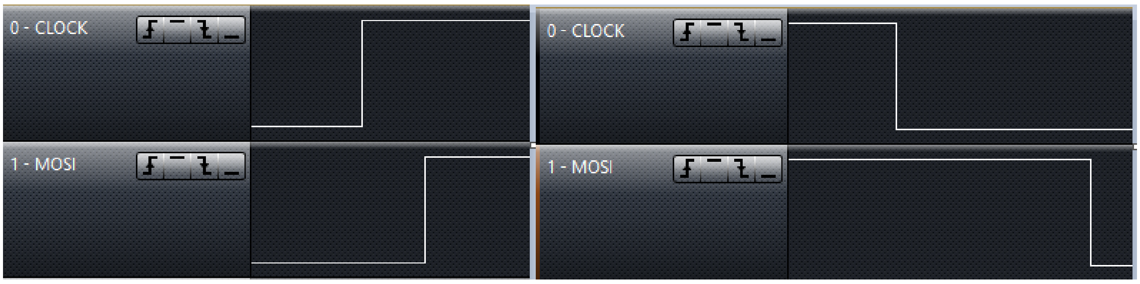


Figure 3.9: Encoder turning clockwise, two steps.

From this graphs, taken with a logic analyzer, the designer programmed the driver to use the encoder as the input device for the console.

Other:

All the non described items, have the same characteristics as in the section 3.3.

3.6 EMITTERS PCB

The emitters PCB will consist in the IR LED's, and the connector to the controller. The description of the connector was already given in the section 2.3.5, so there's only left to talk about the LED's which are **VSMB2000X01,** some of its characteristics are:

- Peak wavelength 940 nm (infrared range).

- High radiant power.

- Angle of half intensity 12º.

- Dimensions 2.3 x 2.3 x 2.8.

And those were the main reasons to choose this IR LED, to keep the form factor of the device as small as possible there was a need of small devices, and was important to keep the angle of the beam as small as possible to avoid interferences with the receivers. The anode of the IR LED's is connected to Vcc, while the cathode is connected to the drain of the FET's from the controller unit, so when the FET's are active the cathode gets connected to ground and the current flows, limited by the current limiting resistors.

So let's check the power consumption of the emitters:
Taking this data from the datasheet:
- IF(max) = 100mA (IFM(max = 200mA)) maximum continuous forward current and peak.
- Vfmin = 1.15V

if the Voltage supplied to the LED's is 3.3V:
VCC = 3.3V, VF = 1.15V
so Rlimit = (vcc- vf)/Imax = (3.3 - 1.15)/0.1 = 21.5 Ohm
and then Prlim = I^2*R = 21.5*0.1 ^2 = 0.215 W
added to Pled = V*I = 1.15*0.1 = 0.115 W
So the power draw for each LED and resistor is = 0.330W

Two LED will never be active together, so it means the power draw of all LED's will be maximum, the same as one LED active all the time.

In case the voltage is 5V:

VCC = 5V, VF = 1.15V
so Rlimit = (vcc- vf)/Imax = (5 - 1.15)/0.1 = 38.5 Ohm
and then Prlim = I^2*R = 38.5*0.1 ^2 = 0.385 W
added to Pled = V*I = 1.15*0.1 = 0.115 W

So the power draw is = 0.5W

The emitters will be switched through transistors, which power consumption should be also considered. The chosen device is the 2n7002, which an internal on resistance of 5 Ohm.

As before said, the maximum current through the emitters will be 100mA, which gives a value for the power consumption of:

P = I^2*R

P = 5*0.1^2

P = 0.05W

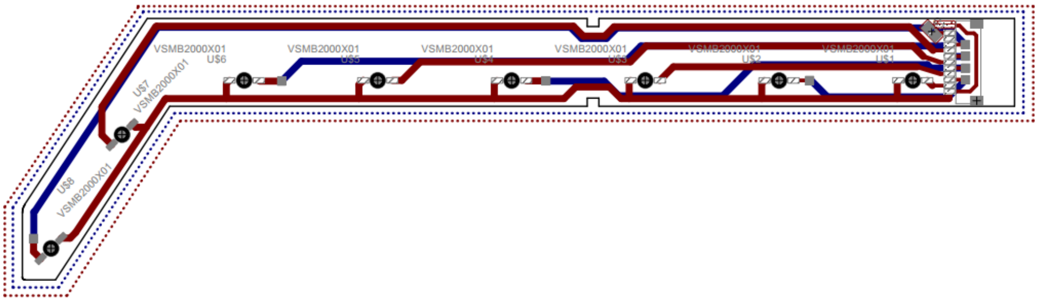


Figure 3.10: Emitters PCB

3.7 RECEIVERS PCB

From the beginning, the system was thought to be tested with 2 types of sensors, so we will get the calculations for both of them.

- Option with phototransistors:

Taking in consideration the calculations shown in the corresponding section, the maximum power consumption will be 25mW per phototransistor, what means 200mW total.

- Option with photo-receiver:

The power consumption of this device comes directly extracted from the datasheet, and is 10mW per device, making a total of 80mW.

Phototransistors:

There are two different ways to use phototransistors, as a linear device, and as a switching device. This depends on the voltage supplied, an own characteristic of the phototransistors, called 'collector light current', which defines the maximum current through the phototransistor for the maximum lighting, and the voltage applied.

The rule to define one or other mode is the following:

Vcc > R*Ica --> we never get into the saturation area, so it works as a linear device.
Vcc < R*Ica --> at maximum luminosity we are saturated. So the formula to calculate the proper resistance will be:
R > Vcc/Ica
Using this formula, with our given values(Ica = 6mA, Vcc = 5V):
R > 5/0.006 = 833 Ohm

This is the minimum value to get into the saturation area with the maximum luminosity detectable by the phototransistor, but by setting bigger the value of R, is possible to switch the phototransistor at lower values of luminosity. To set the proper value for the application, some tests should be done, but an approximate value of 1KOhm will be taken for the first tests.

The two problems that can arise through testing are:

- The LED is not bright enough to saturate the phototransistor (there's a need of a more powerful LED).
- The environmental light saturates the device (reducing the value of the resistor could solve this)

Take in consideration a possible variation in the voltage to a 3.3V power source, which means:

R > 3.3/0.006 = 470 Ohm, so with a 1kOhm resistor we will get in the saturation area at the half of the maximum luminosity of the phototransistor.

Photoreceivers:

The photoreceivers, are slightly more sophisticated devices than the phototransistors, and include generally a block diagram as the one in figure 3.11.
Instead of just sensing the IR light level, the IR receivers, need a modulated IR signal to be excited, this has some advantages, for example, IR noise light immunity, but also means the emitters need to generate this modulated signal.

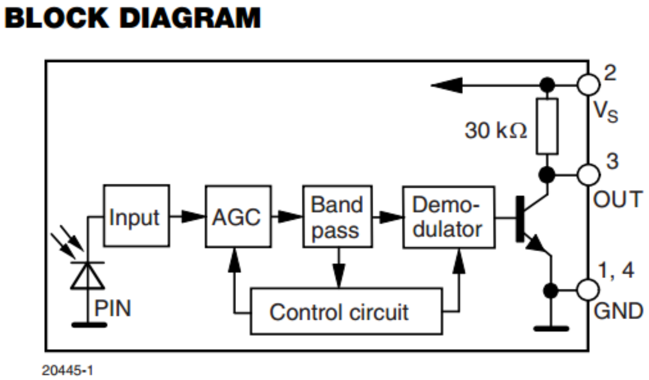


Figure 3.11: Photoreceiver block diagram.

As can be seen on the block diagram the system has integrated pull up resistors, so there's no need for external ones, which will not be soldered in the control PCB when used with photoreceivers.

The device used for this project will be the **TSOP77436**, which has a modulation frequency of 36KHz

The power consumption given by the datasheet of the device is 10mW, what means a maximum of 80mW when all 8 receivers are powered. Below the previously maximum consumption expected, which was 100mW.

3.8 WIRING:

The wiring between the sensors and the controller, but also the wiring used to connect the controllers to the central console is something to take in consideration.

Due to the limitation given by the connectors used (SHR-11V-S), the wire to be used, for the sensor-controller connection, will be the recommended by the manufacturer of the connectors, which is in the range of AWG 32 to AWG 28.

The position of the different pins on both PCB's were chosen to be able to crimp the wires with a simple correspondence, meaning this, that the pin number in the sensor PCB and the control PCB is the same, or inverted, so the last pin on the receivers, correspond to the first pin on the console, and vice-versa. This is an important fact, so it will be easier to find already crimped wires following this specification, than a random disposal of the pins. This will also reduce the manufacturing costs.

For the case of the wires which connect the console and the controllers, the connectors were chosen to be able to replace the wiring with ease, so the company which acquires this project, can exchange them depending on their needs. Right now, the designer is using 1.27mm pitch 4 poles ribbon cable.

4. SOFTWARE DESIGN

4.1 INTRODUCTION

There will be two main parts in the software design, one regarding to the console, and the other on regarding to the sensor controller.

The chosen microcontroller for this development is the PIC18f4550 from the company Microchip. The reason to choose this microcontroller is the wide previous experience of the designer with this microcontroller.

The software chosen for the development is the MPLAB X Integrated Development Environment provided for free by microchip. The advantage of using this IDE instead of a generic one, is the full integration with the microcontroller programmers Pickit2 and Pickit3 available for the designer, also its code autocomplete capabilities, and multiple file structure organization, also the compatibility with several different compilers, like CCS, C18 or XC8.

The compiler of choice for the previous development of this project was C18, but during the redesign process, the designer decided to change this compiler for a more updated version, which is up to date, in difference with the C18 compiler which is currently deprecated for new projects, and no more technical support provided.

The XC8 compiler is based on the ANSI C standard, with the addition of several specific libraries for the use of each specific microcontroller architecture from microchip, so is possible to access all the peripherals of every device through C libraries, instead of having to program them through assembler code.

4.2 CONSOLE FIRMWARE

The main tasks of the console firmware are:

- Configure and manage the user interface, which consist in several input and output devices to be controlled by the user, or to display information to acknowledge the user.

- Give access through the user interface, to all the configuration parameters to be used in the different assembly types.

- Control the assembly process, meaning this, to check if the assembly workers take the right amount of parts and on the right order to get a correct assembly.

- Block the assembly system in some way, not allowing the assembly workers to continue with the process, before the supervisor checks the assemblies which could give place to an error.

4.2.1 USER INTERFACE:

Those are the input devices the users can access to:

Encoder with button:

Turning this device right or left, the user can go through the different menu options, pushing the button contained in the encoder starts the selected process for example to start the assembly process, or to change the configuration parameters.

Secondary button:

Pushing the button returns from the current option back, stopping the process without saving any information changed. Together with the "Encoder with button" is enough to move back and forth through all the console options.

Locker:

The locker is used to avoid the assembly workers to change the different configuration options, so once the locker is closed, <u>all the configuration functionality disappears from the console options.</u>

The menu options are intended to be only user by the supervisors, to properly set up the machine, and to unlock it in case there's any mistake in the assembly.

And those the output devices:

Screen:

Used to display most of the relevant information of the system, also to navigate through the different options. Most of the screen handling is hidden in flowcharts, due to the fact the libraries used to manage such events, were programmed by the designer, but are generic for different projects, so they're out of the scope of this text.

Power LED:

Simply a white LED, which shows the system is already powered on.

Run LED:

Colored led which blinks while the microcontroller is performing tasks, so if the LED stops blinking means the system got stuck. Useful for debugging tasks, but also just in case there's a critical error during the process, the user can appreciate the machine is stuck, and restart it.

Buzzer:

Used during the assembly process, to acknowledge the assemblers the detection, and also to be used as an alarm when there's a fail in the assembly process.

Chain(relay):

The designed console, could be connected also to other devices that are checking other parts of the assembly process, and this is the way they communicate. When the contact change from its normal state, it means there's a problem in the process, and it will only return to the original state, when the supervisor unlocks the system through the locker.

4.2.2 MENU OPTIONS AND CONFIGURATION PARAMETERS:

All the configuration parameters explained in this section, will be stored in global variables, so there's easy access to them from any part of the program.

In the figure 7.1 can be seen the different options through which the user can navigate.

Let's get a little bit more in detail about those options:

4.2.2.1 Firmware version

Allows you to check the current firmware version installed in the device, in case the company which ordered the project decides it on that way, this could be changed to a text displaying the name of the company or any other text.

4.2.2.2 Assembly start

Shows on the screen the possibility to start the assembly. pushing the enter button starts the assembly process.

4.2.2.3 Assembly

Once here we are inside the assembly process itself, and it will be ruled by the flowchart attached within the figure 7.6.

4.2.2.4 Configuration menu

Allows the user, by pressing the 'enter' button to get inside the configuration menu, letting the user move through the different options.

<u>Attention!</u>

The Configuration menu is not intended to be used by the workers involved in the assembly process, but for the supervisors, so this menu will be hidden while the locker stays open.

4.2.2.5 Configuration option display

The options going from 'NUMBER OF BOXES' to 'ERROR STATISTICS' are an intermediate step to get into the actual configuration process, used to display the corresponding name. Regarding to their functionality they can be grouped all together.

4.2.2.6 Configure Number of boxes

This option allows the user to change the number of boxes the system will use in a specific assembly, each box represents a different part. The current system will have capability for up to 4 different parts, but it could allow up to 8 boxes with the current console hardware, and up to 16 doing minor design modifications. Those modifications will be done only under demand.

Turning right or left will increase or decrease the number of boxes, pushing 'enter' will save the current value, 'back' will leave the menu without saving.

The maximum value of boxes will be kept in the range before defined.

4.2.2.7 Configure parts per box

Through this menu option, the user will be able to decide how many equal parts will be used in the assembly(extracted from the same box).

'Up' and 'Down', will increase/decrease the number of parts in the currently displayed box. 'Enter' will move to the next box. Once in the last box, it will quit automatically. 'Back' will quit the configuration menu without saving the currently displayed number of parts.

4.2.2.8 Time between boxes/inside box

Used to determine the timings the assembly workers can stay idle without taking the next part of the assembly.

The behavior of this configuration will be the same as the previously explained in the section 4.2.2.6 , but with a different maximum and minimum ranges.

4.2.2.9 Sound

Allows to set the alarm sounds active/inactive depending on the preferences of the user. 'Up' and 'Down' will toggle the option, whereas the 'Enter' button saves the option and quits, and the back button quits without saving.

4.2.2.10 Error Statstistics

Inside this option is possible to check the number of faults committed after the last counter reset. To reset the counter turn the encoder left, turning right has no effect, 'Enter' and 'Back' options share the same behavior, going back to the configuration menu.

<u>note:</u> In future versions of the software there will be several other error statistics.

4.2.3 ASSEMBLY PROCESS AND SYSTEM LOCKING

The assembly process, which is the main aim of the design, is thought to proceed as in the flowchart given in the 7.6, but let us explain it normal language:

Once the machine is switched on (with the locker closed), the only available options are the firmware, and the assembly start, pushing 'Enter' on the assembly start options, the system will show the number of a box, from which the worker needs to extract a part, and it will continue showing the same box number until, as many parts as needed for the assembly are extracted. Then the number of box will change, and the worker should then repeat the process with the box with the corresponding number shown in the screen. Once all parts from all boxes are extracted, the process starts again.

If there's a detection in a box which is not the one shown, or there's a try of a simultaneous extraction from several boxes, the system will display the error and get locked.
In case the time assigned to extract the part from the box and assemble it expires, or the system is detecting a hand/object inside the box for too long, the system will behave in the same way as before mentioned.

Once the system is locked, the it will change the state of the relay, locking also the other processes in the assembly chain. Then, the system will keep locked until the supervisor unlocks it using the provided keys for the electric locker. Then, the worker will be able to start the assembly again.

4.3 CONTROLLER FIRMWARE

The goal of the controller firmware, is to generate the proper signal on the emitters to excite the receivers, and to capture the value of the receivers, so is possible to know if there's any cut on the beam between the emitter and the receiver. This is the basic way to find out if there's any interaction inside the boxes. This method starts being quite simple, but it will be subject to changes, to improve its reliability.

This process should also toggle, from time to time, the RUN LED embedded on the PCB, to easily detect the proper function of the microcontroller.

To try to get a better detection, there are some characteristics to remark, to clarify the some of the characteristics of its function.

The receivers work with 36MHz light, what means there's a need to generate at the LED's a signal with the same frequency to excite them. This will be defined as a burst.
Given the information on the datasheet, it's not possible to emit continuously over the sensors, or they will lose their sensitivity, what means there will be a pause between bursts.

When there isn't any strange object (like a hand) inside the container, the receivers get the light from the IR diodes, but in a multiplexed way, what means, each of the detectors receives a burst, pauses, and then the next detector repeats the same process in a continuous cycle. So, during the time the IR LED is emitting directly to the receiver, in the case there's nothing cutting the beam, its output level will be LOW. and HIGH during the rest of the time to perform a full multiplexed cycle.
So the moment to detect if there's a cut on the beam, meaning this a strange body inside the container(like a hand, for example) is while generating the burst. (This process is also documented in the figure 7.12)

Every time the IR LED gets high, to generate the burst, the output of its corresponding detector will be checked, and a variable will be increased if the receptor is low.

If after finishing the whole burst, the saved variable goes over a predefined threshold, it will count as a positive object detection.

Once there's a positive detection, the cable connected to the central console will get high.

The system will continue sensing for a positive detection, while holding the console cable high. At the point the sensing gives as a result a negative in the detection, the system will wait for a defined time, expecting a second negative detection to pull down the console communication pin. This pause and double check, is a way to debounce the sensor system.

As can be seen in the figure 7.12 the LED blinks every defined number of detection cycle, defined by the variable max in the LED toggle flowchart. This means, the LED isn't blinking on a fixed timing, but depending on the timings of the sensing process.

5. PROTOTYPE AND PRODUCTION

5.1 MECHANICAL PARTS

To check the proper functionality of the parts, as a part of the redesign of a system is important the use of prototypes. The prototypes manufactured for this project, are done with two different systems, laser cut parts, and 3D printed parts.

Laser Cutting:

The laser cut manufacturing, is usually used with parts which have a flat dimension, so they can be produced by cutting them away from a raw sheet of material. It's possible to get the parts directly from the machining provider, or to get the raw material and pay the laser cutting service per given time. In the case of this project, the designer had the access to a Laser cutter, and had the knowledge to use it, so the prototypes were manufactured in a timed service. The parts prototyped with this method are "console box front" and "console box back".

Figure 5.1: Laser cut acrylglas.

In the case of a mass production, is always better to outsource the service and relay in the hands of professionals, it will be easier and cheaper.

3D printing (FDM):

The definition of 3D printing, is a vague conglomeration of very different manufacturing techniques with something in common, they're additive techniques, and this means that, instead of removing big quantities of materials from a raw block, they add small quantities until the desired part is generated.

Three examples of these techniques are:

- SLA(Stereolithography):
which uses a laser to cure a photosensitive polymer, by layers, a slow method with very few and expensive material choices, but good print quality.

-SLS(Selective Laser sintering):
Generates the part melting selectively polymer dust. Giving parts of good quality, small tolerances, but rough surface finish.

-FDM(Fused melted deposition):
The additive manufacturing most diffused method, using an extruder to melt a plastic filament which conforms the parts. It's a method with low reliability and low quality prints, but is far away the cheapest, in terms of machinery and material.
This will be the method used for the production of the following prototypes.
"Console box top", "console box bottom", "control box top", "control box bottom", "sensor box right" and "sensor box left".

Figure 5.2: FDM printed part.

Injection molding:

For a possible mass production, the preferred production method for the 3D printed prototyped parts will be the injection molding. This has some implications on the mechanical design of the parts, like minimizing the undercuts, and draft all the parts to ensure the demoldability. Those and other requirements can be seen on the included offers, used also for the costs estimation.

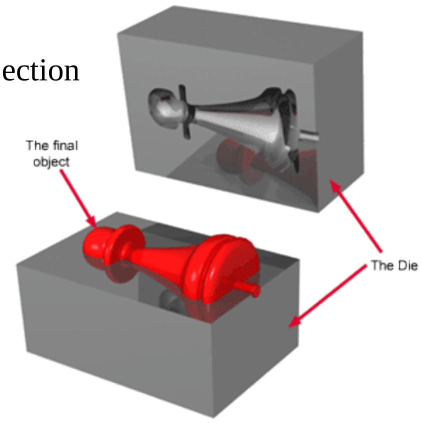


Figure 5.3: Injection molding.

5.2 PRINTED CIRCUIT BOARDS

Gerber files:

The first step to manufacture a PCB, usually is to get from your preferred PCB design software, the GERBER files, which is a de facto standard for the PCB production. Usually there's also the need to add the Excellon files, which refer to the drilled holes.

PCB Manufacture:

Once the CAM files are ready, there are lots of different online service in which you can manufacture the PCB's, for this project, the designer checked several services around europe and asia, and besides the wish of the designer to manufacture the PCB's in the EU, but the price difference is so humongous comparing to the Asian market, that was impossible to the designer to afford EU manufacture.

Hand soldering:

For the prototypes, the part assembly process and soldering was handmade, due to the excessive cost for a small production through other methods like the pick and place system.

Pick and place:

The pick and place systems, are the preferred for a medium to high production quantities, it gets discarded for the prototypes due to the high initial costs of the technology. Those systems automatically place all the components over the PCB, which will be afterwards soldered inside a PCB oven. Let us see an example of this machines in the figure 5.4.

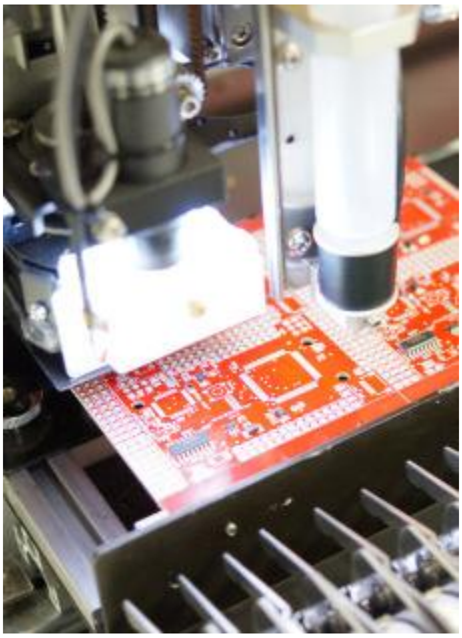


Figure 5.4: Pick and place machine.

6. TESTS AND MODIFICATIONS

6.1 PROBLEMS ON THE BASIC FUNCTIONALITY

6.1.1 HOT PLUGGING AND NTC'S

In lots (but definitely not in all) modern electronic systems, is possible to directly plug some parts of the device while it's connected and working. This action is known as hot plugging. When designing the device described on this project, it was never taken in consideration, but simply expected to work on this way.
If plugging directly the sensor boxes onto the console, the power draw of the boxes, and the connection process itself, generates large voltage and current spikes, which generate resets on the microcontroller of the console.
To avoid this kind of behavior and enabling a real hot plug system, the use of NTC's in series to the power pin which goes to the different boxes, will make the current to be small when the boxes are connected, and while the heat on the NTC's increase, their resistance will go down, letting the current rise slowly until a stationary state, in which the power draw of the NCT will be negligible.

6.1.2 RESET PROBLEMS, WATCHDOG

There are lots of different reasons why a microcontroller can get stuck, As explained in the previous section big variations in the power draw, generating current spikes is one of them. But also for example, a close device, generating EMI (electromagnetic irradiation) or a bad code, could paralyze the microcontroller. To avoid that, there's a special device on the microcontrollers called watchdog, which can generate an automatic reset on the microcontroller on a regular time basis, when it's timer is not software reset. This is a fantastic method to get a reliable device, but it requires to structure the code in some way which allows to perform all the tasks before the watchdog timer overflow.
Unfortunately, the code wasn't properly structured for it, and the designer doesn't have the

time to modify the code before the first release, but will probably be modified in case there's a second release.

6.1.3 CONNECTORS

During the testing phase, some problems with the IR LED shown up, they were randomly working depending on the position of the PCB, which in the beginning look like a crimp problem, the designer had to crimp all the wires on his own, with tools which were not adapted to this kind of connectors, which is an inherent focus of troubles and errors, but at the time, it was simply the only possible option. Finally emerged the real cause of the problem, which was a bad solder, another of the most common problems, due to the hand soldering of very small components done by the designer.

6.1.4 IR LED EXCESSIVELY POWERFUL

On the calculations for the current draw for the LED's was taken the maximum possible brightness of those, thinking that this would be the best option to improve the reliability of the beams, but several problems came into view.
The excess of power of the LED's were causing lots of reflections inside the containers, which meant that all the receivers were active every time an LED was flashing.
There's a consideration ignored before, which is the fact that HUMAN FLESH IS ALMOST TRANSPARENT TO IR LIGHT. What means there's a need to emit at very small power, so the goal of detecting a hand inside the containers is accomplished.

6.1.5 ERROR IN THE PCB LAYOUT

There was an error in the footprint of the VTX-214-010-112 device, the issue was the footprint was mirrored, so the power supply could be properly connected on the other side, the problem is, doing so, means the dimensions of the PCB change totally, making impossible to fit inside the console box.
This problem was solved soldering wires to the power supply to replace them on the solder of the PCB.
The proper way to solve this problem would be to modify the footprint and redesign the CPB, but there was no time to wait for the manufacture of the new board, so the designer of this project decided to go forth with the current PCB design.

6.2 FURTHER MODIFICATIONS

6.2.1 CONNECTING MORE SENSOR BOXES

There is the possibility to connect more sensor boxes performing a modification in the software and adapting the wiring between the console and the controllers, using the second I/O pin every box port has available, currently used to ensure the boxes are connected.

6.2.2 USING I2C PORT TO CONNECT WITH THE CONTROLLERS

This possible modification was taken in consideration from the beginning of the design of the PCB's so by means of the internal DIP switches on the console PCB is possible to connect all the controller box ports to the console, in a way that they can make use of the I2C port communication. This feature wasn't tested due to the lack of time before the deadline of this project.
One of the expected problems of this method, will be the maximum allowed wire length, which depends on the value of the pull-up resistors used on the I2C data and clock pins, and the length of the wire used by the communication. Decreasing the speed of the clock signal, will also improve the reliability of the communication.

6.2.3 POSSIBLE WIRELESS COMMUNICATION

A possible wireless communication between the sensor controllers and the console was taken in consideration, adding to the controllers a Lithium Polymer battery, could avoid the need of wiring the system, giving a much better flexibility.
It's possible to notice the footprint of and NRF24L01 on the controller PCB, which was the device intended to be used for that communication. Due to the high power consumption reduction on the IR LED's commented in section 6.1.4, this option is much more feasible, so if there's a redesign on the project, will be oriented on this way.

6.2.4 SPI COMMUNICATION

The previously mentioned NRF24L01, communicates to the microcontroller through SPI port, which in the actual microcontroller isn't compatible with the I2C communication, which implies to change the communication protocol between the LCD screen included in the console, and the microcontroller to I2C, this can be easily done using another PCB previously designed, just replacing the I2C for the SPI module on the back side of the screen.

6.2.5 CHANGE TO ARM ARCHITECTURE

The change in the architecture of the microcontroller, is one of the most critical possible changes, because it will imply a very deep redesign in the project, but if the time would be available, this modification can represent the biggest performance improvement of the system(not functionality improvement, which will be the wireless communication system.)

6.3 TESTS

6.3.1. TEST 1: ENCODER PROBLEMS:

The encoder used for the very first development differs from the currently used. The driver for the encoder, was developed for the former encoder type, so there's a need of modifying the encoder driver to use it with the new model.

After trying to approach the problem in several different ways, gets clear that the modifications to be done, need to be much bigger than expected, declining the designer to make those modifications before the deadline. This modifications could be done when re-writing the console software in a possible next revision.

Besides not totally correct, the console still useable, with some modifications on the encoder driver.

6.3.2 TEST 2: THE CONSOLE GETS STUCK

The console gets stuck randomly from time to time, to solve this there will be a plan to readapt the code to use the watchdog in the next revision of the software, currently not implemented, making the system less reliable.

6.3.3 TEST 3: IR LED'S RANDOMLY NOT WORKING

Using IR light for the development of the sensors, means it's not possible to check the proper function of the LED's just looking at them, for all the checks done to the IR-LED's was necessary the use of a mobile phone with camera, taking the advantage to the fact that most of the camera sensors are sensitive to IR light.

While testing the controller for the first time, the IR LED's weren't working at all. After some time looking for the problem, they randomly started to work. Finding the problem took quite long time, during which some other tests were performed, until the system started to fail again. Finally was found out that the problem was due to a cold solder, made in the pins of the connector of the IR LED's PCB.

6.3.4 TEST 4: SOME RECEIVERS NOT WORKING

The first point to check if the receivers are working properly is to check if they have their outputs high when no infrared modulated light is emitted on them. Checking with the multimeter it emerged that 3 of the outputs weren't high. After checking the conductivity of some tracks on the PCB, was found out that some pins of the sensor weren't in contact with their pads, due most probably to a cold solder. After re- soldering the faulty sensors, were tested again, giving the right values.

6.3.5 TEST 5: IR LED LIMITING RESISTORS HEATING IN EXCESS.

To check the code of the controller for the first time, and to be able to clearly see through the camera the IR LED's were working, the LED's were flashing without modulation, which means they were always active, obligating the LED's and their limiting resistors to dissipate much more power, heating up fast to their maximum allowed values. Cutting off the power prevented the LED's to blow up.

6.3.6 TEST 6: DRIVING THE LED'S WITH THE TEST BURST.

As written in the datasheet of the receiver, there's a test burst which ensures the sensors will be excited. The code to generate such burst was loaded on the microcontroller to drive only one IR LED. When measuring the outputs of the receivers, all of them were low while the test LED was emitting the burst, when the expected result was to get this signal only in the receiver which was coupled with the active IR LED. Moreover, cutting the beam of the LED with any object, doesn't change the output of the receivers. Further tests shown there are some objects that can stop the light to excite the receivers, but only when in a special angle which directs orthogonally all the reflections of the IR beams, and with very opaque objects.   The result of the experiments exhibits two problems:

- The IR LED's are extremely powerful for the requirements of the IR barrier, <u>producing</u> lots of <u>reflections</u> which excite all the receivers, not being able to differentiate which IR LED emits the beam, being this a possible error focus.

- The <u>human flesh is not as opaque to IR light as it is to visible light</u> what means that even if a hand is blocking the beam between an emitter and a receiver, the sensor could miss its detection.

Drastically reducing the emission power of the LED's could solve the problem, so the current limiting resistors for the IR LED's were replaced for 8.2kOhm resistors.

6.3.7 TEST 7: DRIVING LED'S WITH LOWER CURRENT

After the replacing of the limiting resistors with the new value of 8.2kOhms, a finger can easily break the beam of the IR LED's. The number of receivers excited for each LED still isn't only one, but three. Besides this, the excited receivers always follow a predictable pattern, being the adjacent ones on both sides, what means that in the corners, only two receivers are excited. This fact, can become an extra feature if properly managed by software, because it allows to detect if the oblique beams gets cut, which could allow to measure the size and the position of the object cutting the beam.
Besides the system is already useable, there are some problems driving the last two IR LED's, on the outer side of the container, which aren't working properly.

6.3.8 TEST 8: LIGHT SOURCE INTERFERENCES

Two possible light sources which can cause interferences on the receivers, are the fluorescent lamps and the IR remote controls.

To check if the receivers were catching these interferences, a fluorescent lamp was disposed as close as possible to the receivers, focusing its light directly to the receivers. There wasn't any difference in the functionality of the system while the fluorescent lamp test.

An IR remote control, was also used to interfere with the receivers, pointing the emitter to them. While in a long distance, the remote control doesn't affect to the receivers, but in a very short distance, the emission of the remote control can cause interferences, generating false positive and false negative detections, but if the distance between the remote control is more than approximately 500 mm the interferences are not powerful enough to interfere with the receivers.

The conclusion is that the interference level to cause a malfunction in the receivers by fluorescent light is negligible, and the interferences caused by a remote control, are not intended to be in the scope of the system, and much less, as close as they need to be to cause such interferences.

7. FLOWCHARTS

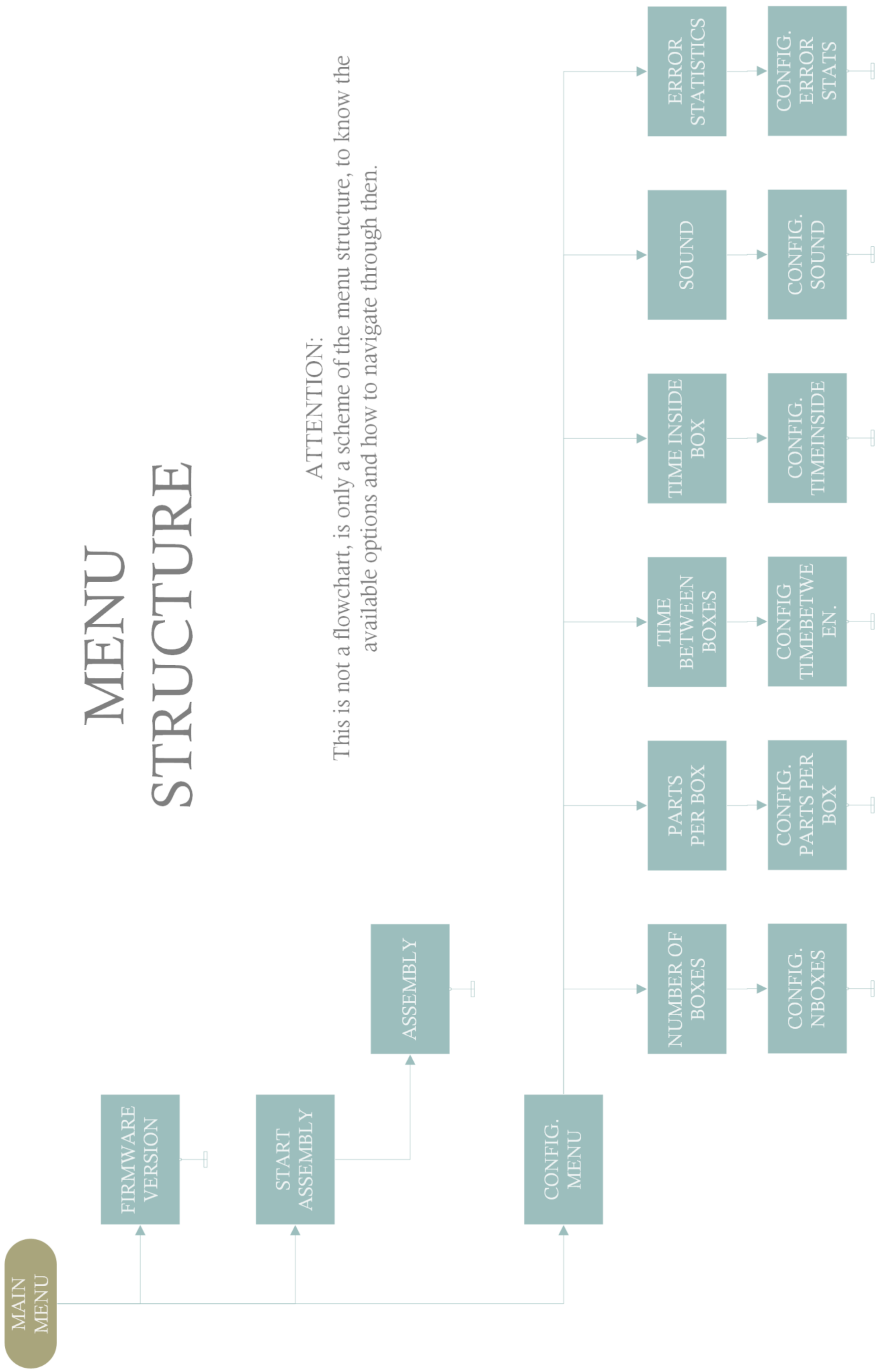


Figure 7.1: Menu structure.

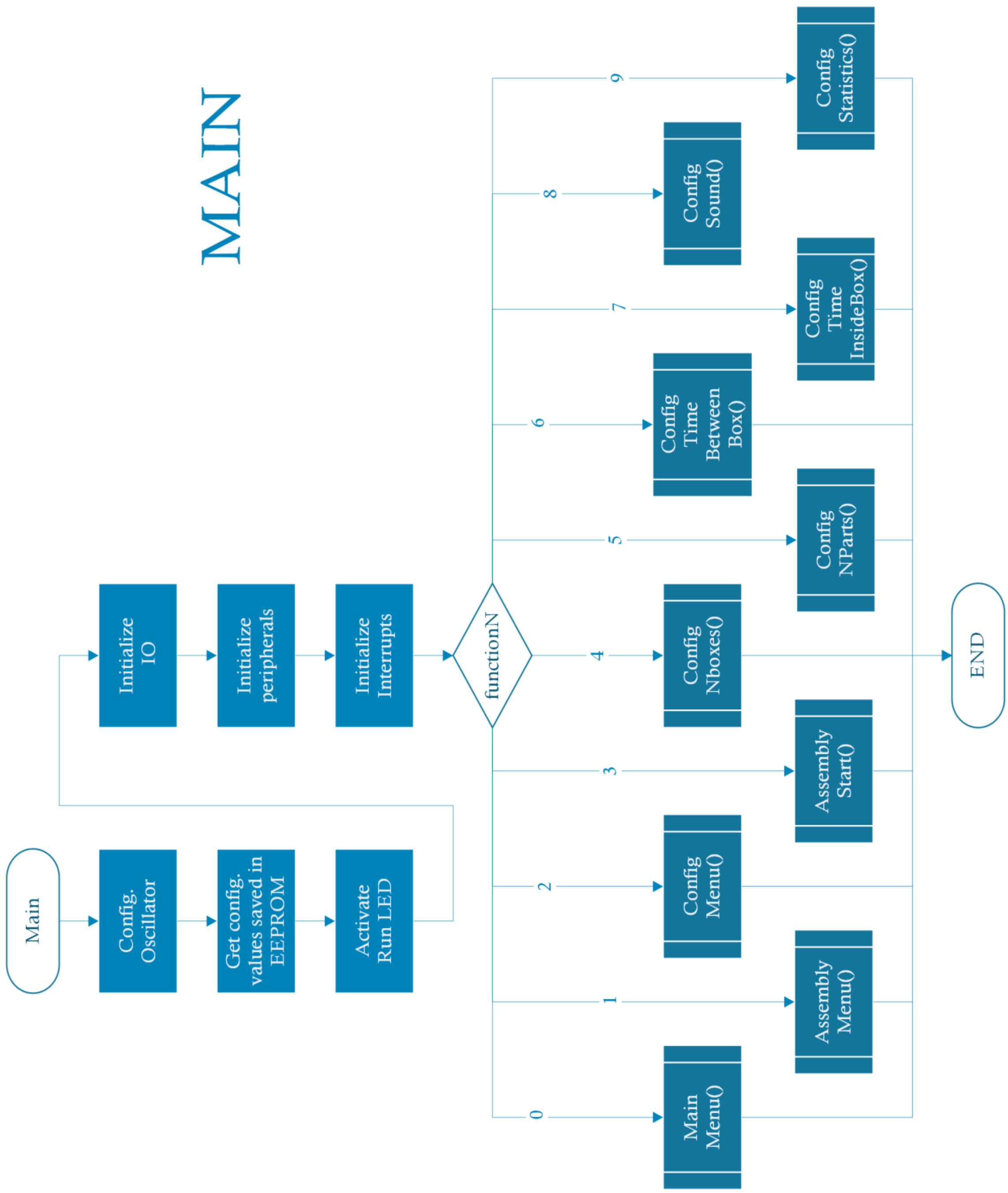


Figure 7.2: Main function flowchart.

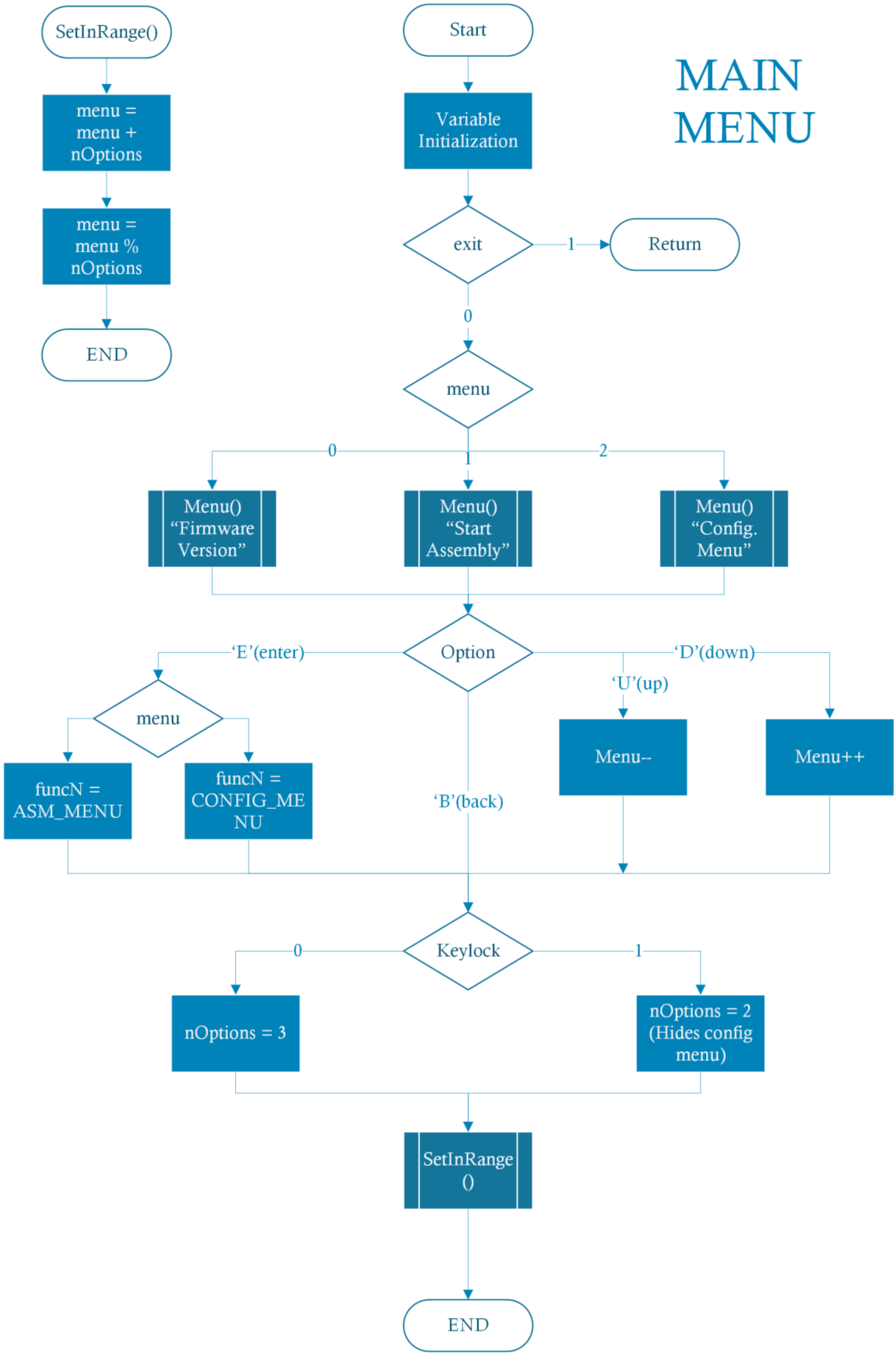


Figure 7.3 : Main menu function flowchart.

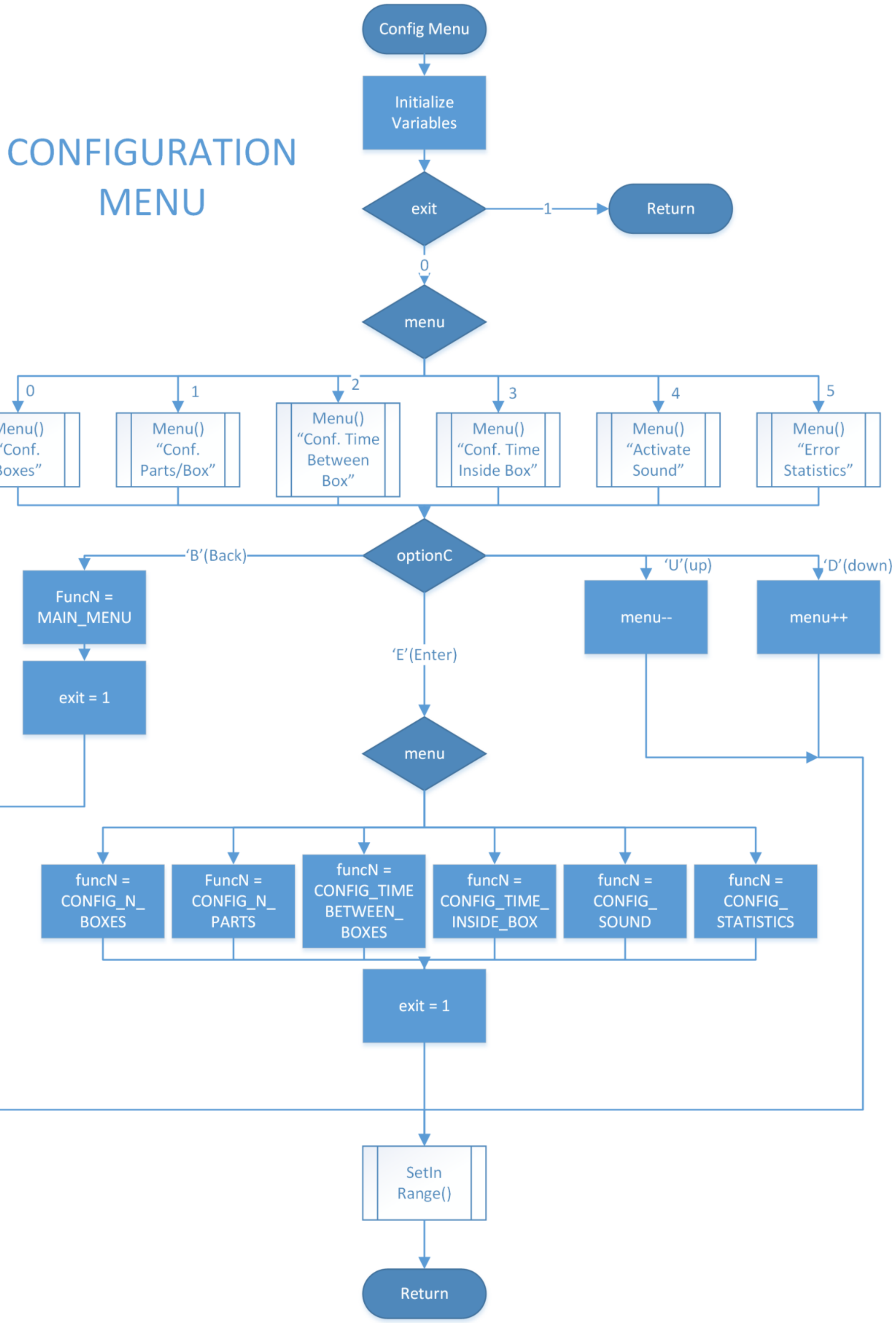


Figure 7.4: Configuration menu flowchart.

ASSEMBLY MENU

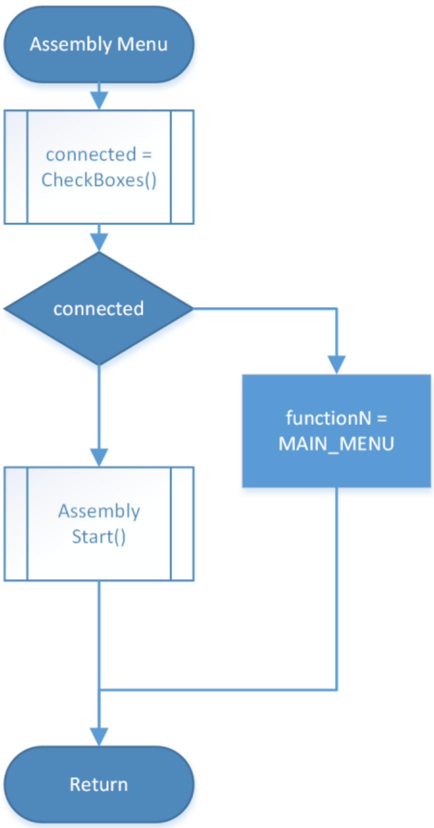
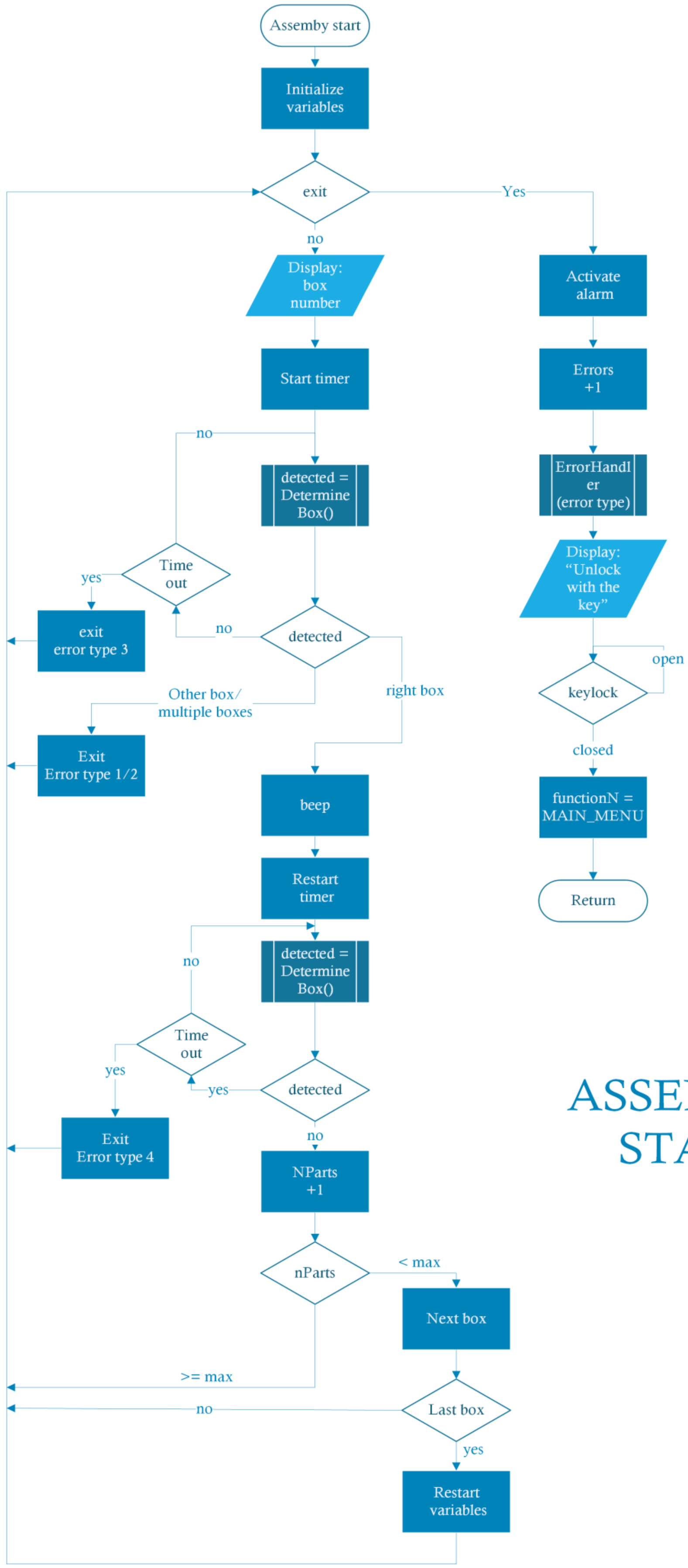


Figure 7.5: Assembly menu flowchart.



ASSEMBLY START

Figure 7.6: Assembly process flowchart.

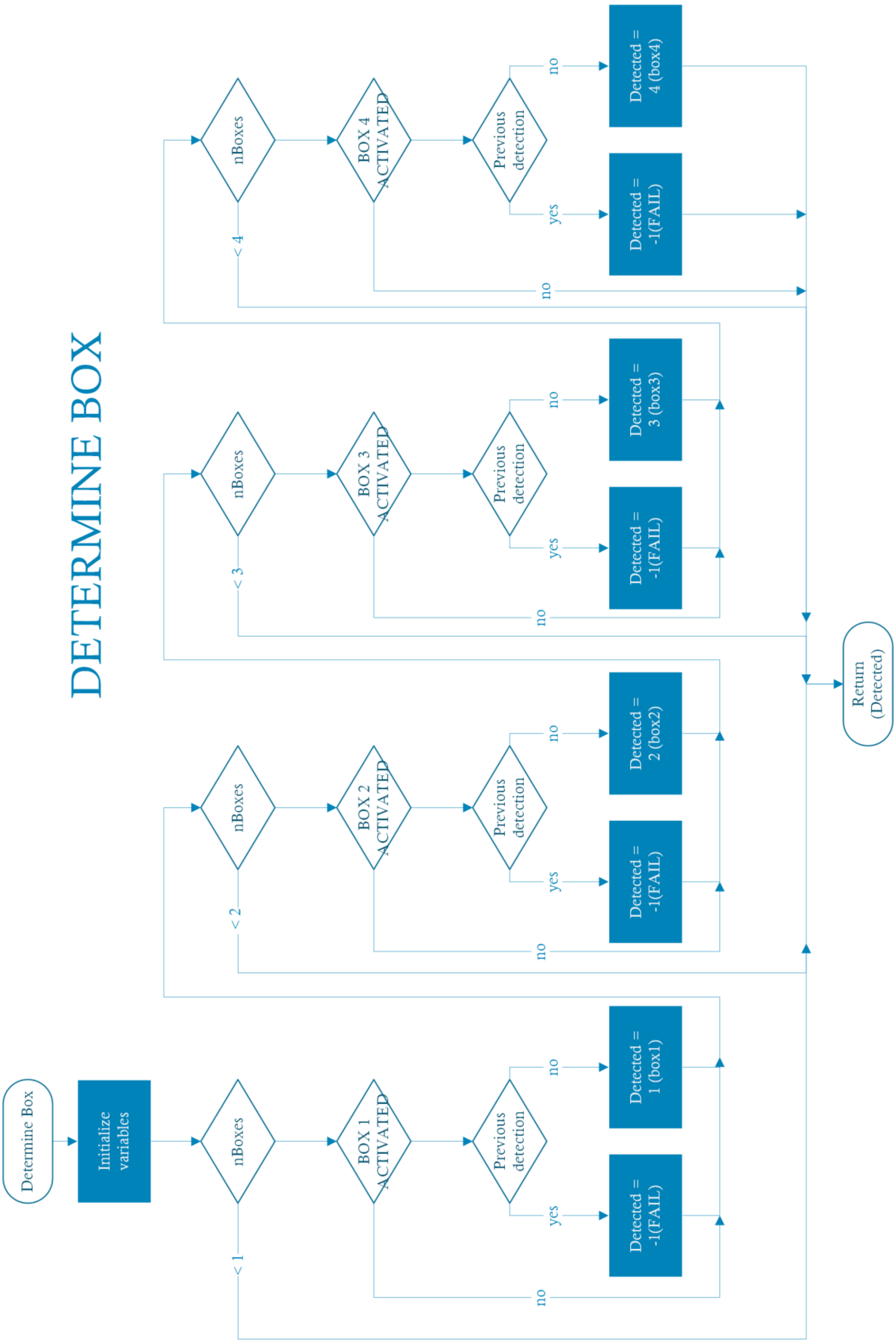


Figure 7.7: Determine box process flowchart.

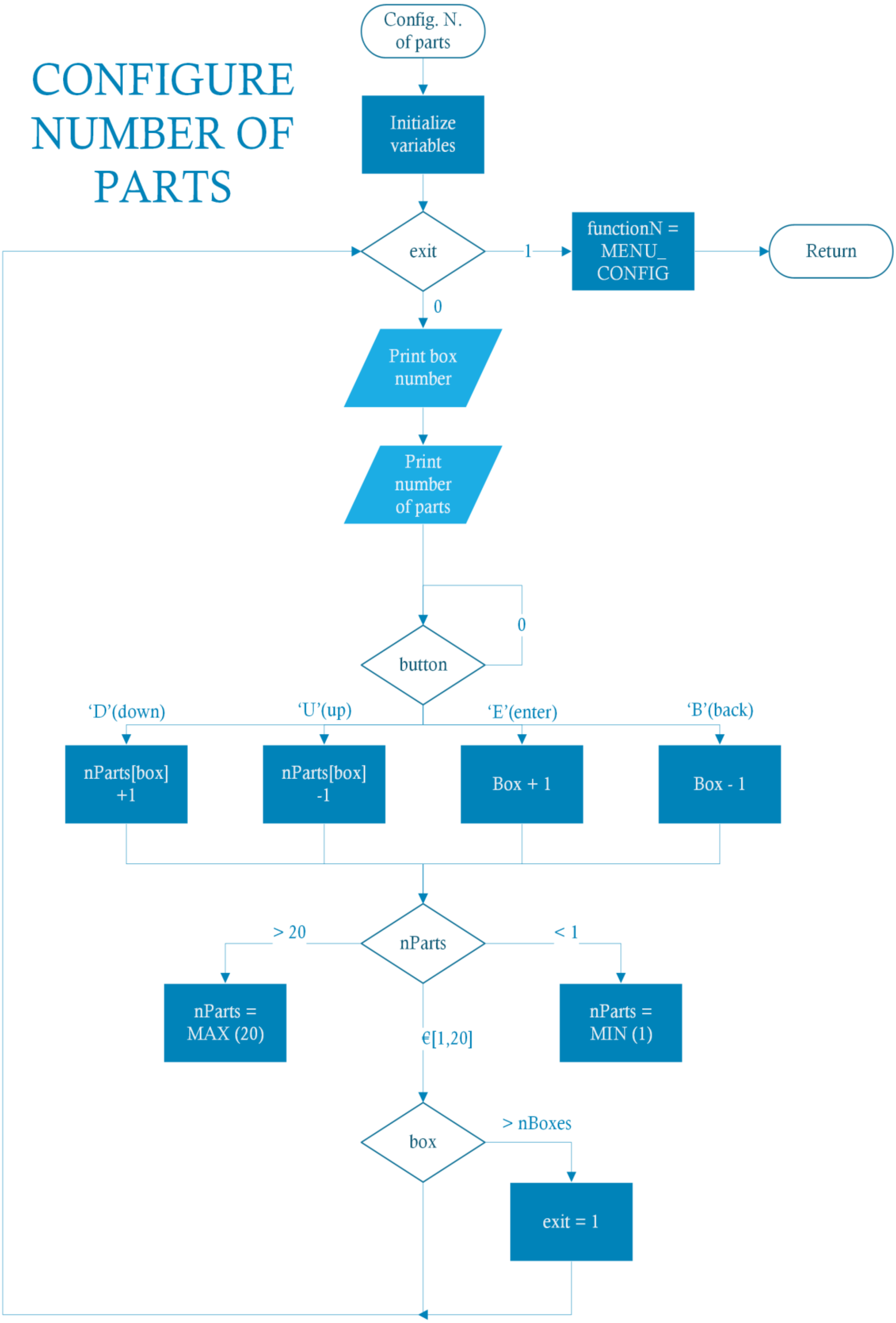


Figure 7.8: Configure number of parts flowchart.

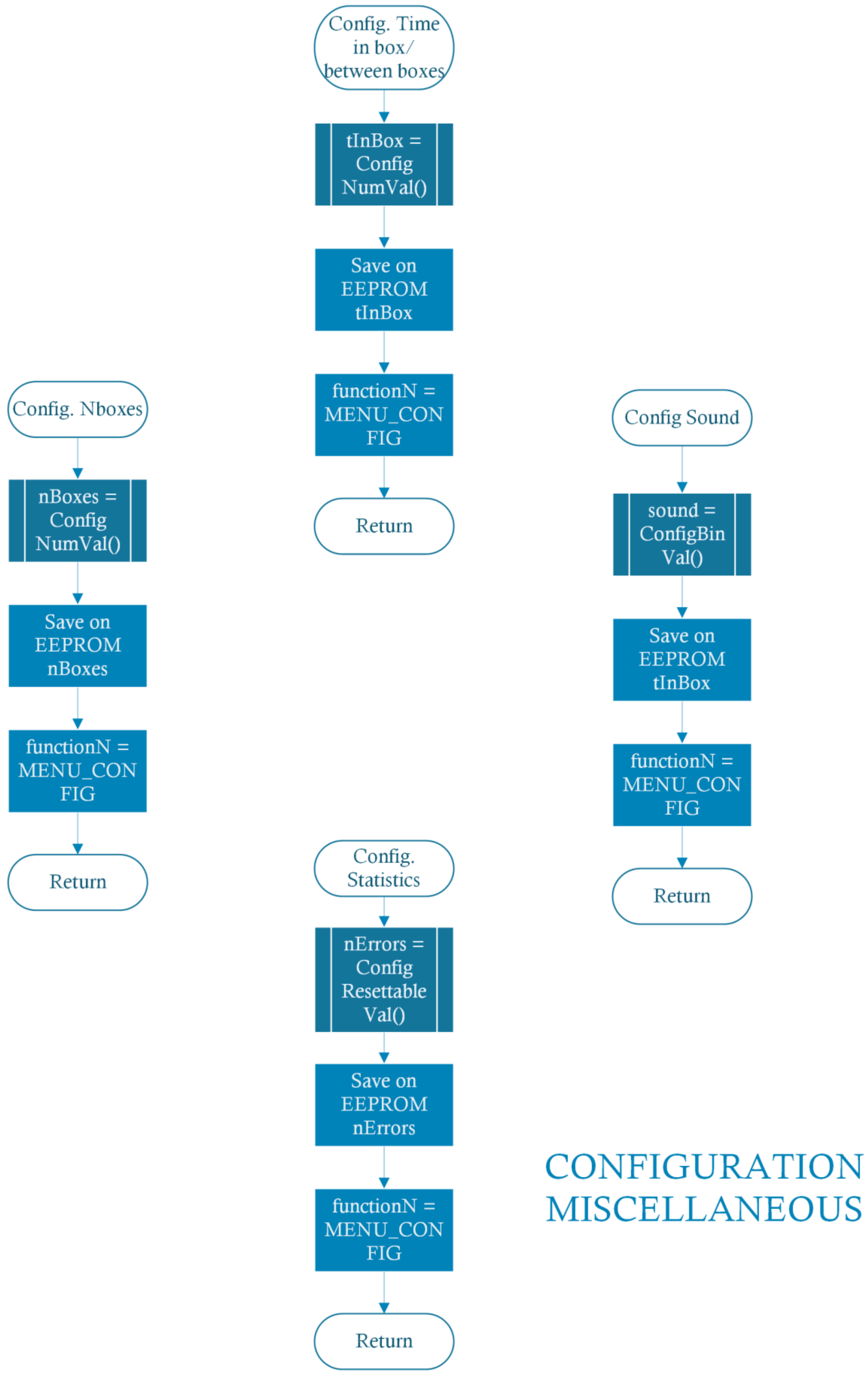


Figure 7.9: Flowchart of miscellaneous configuration options.

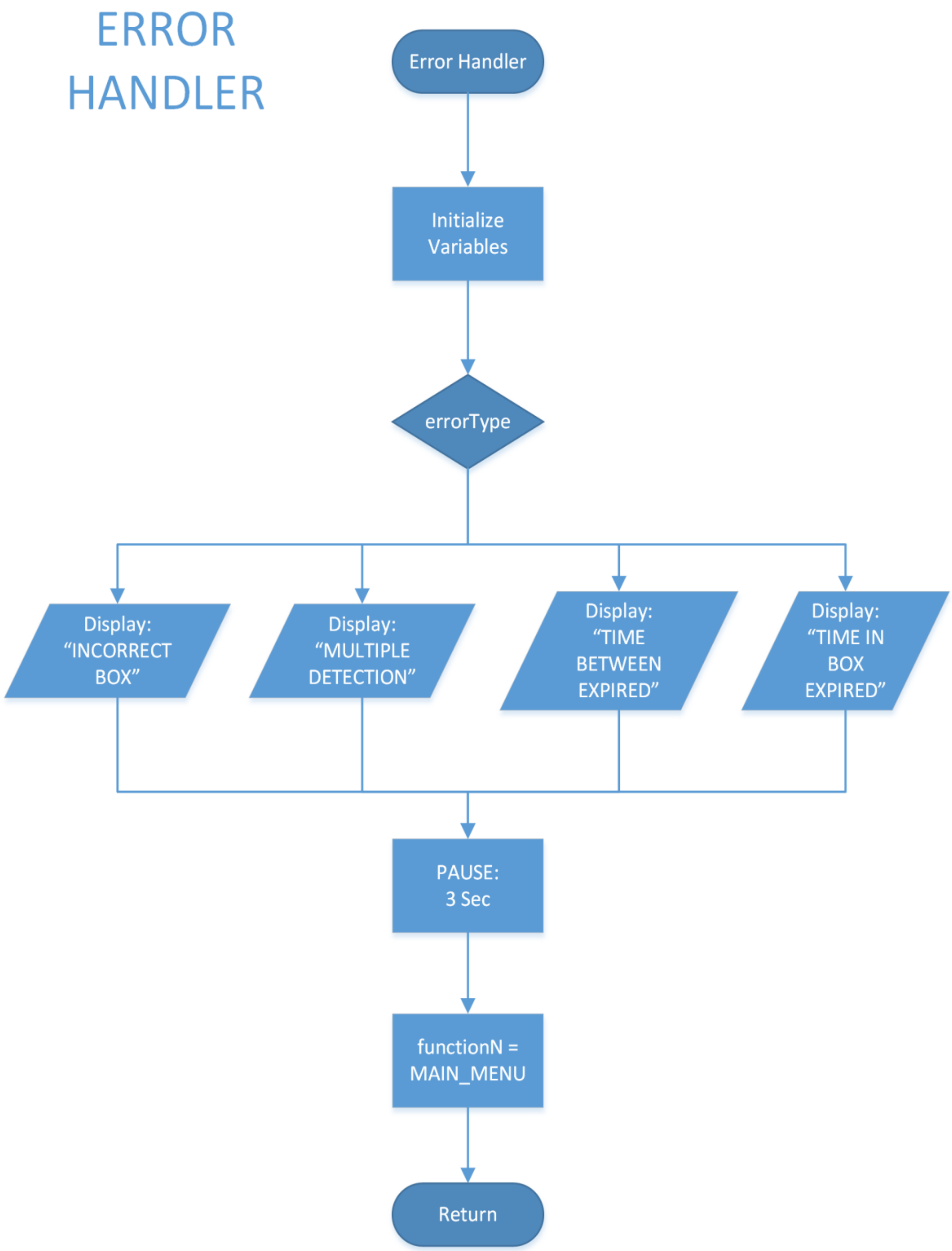


Figure 7.10: Error handler flowchart.

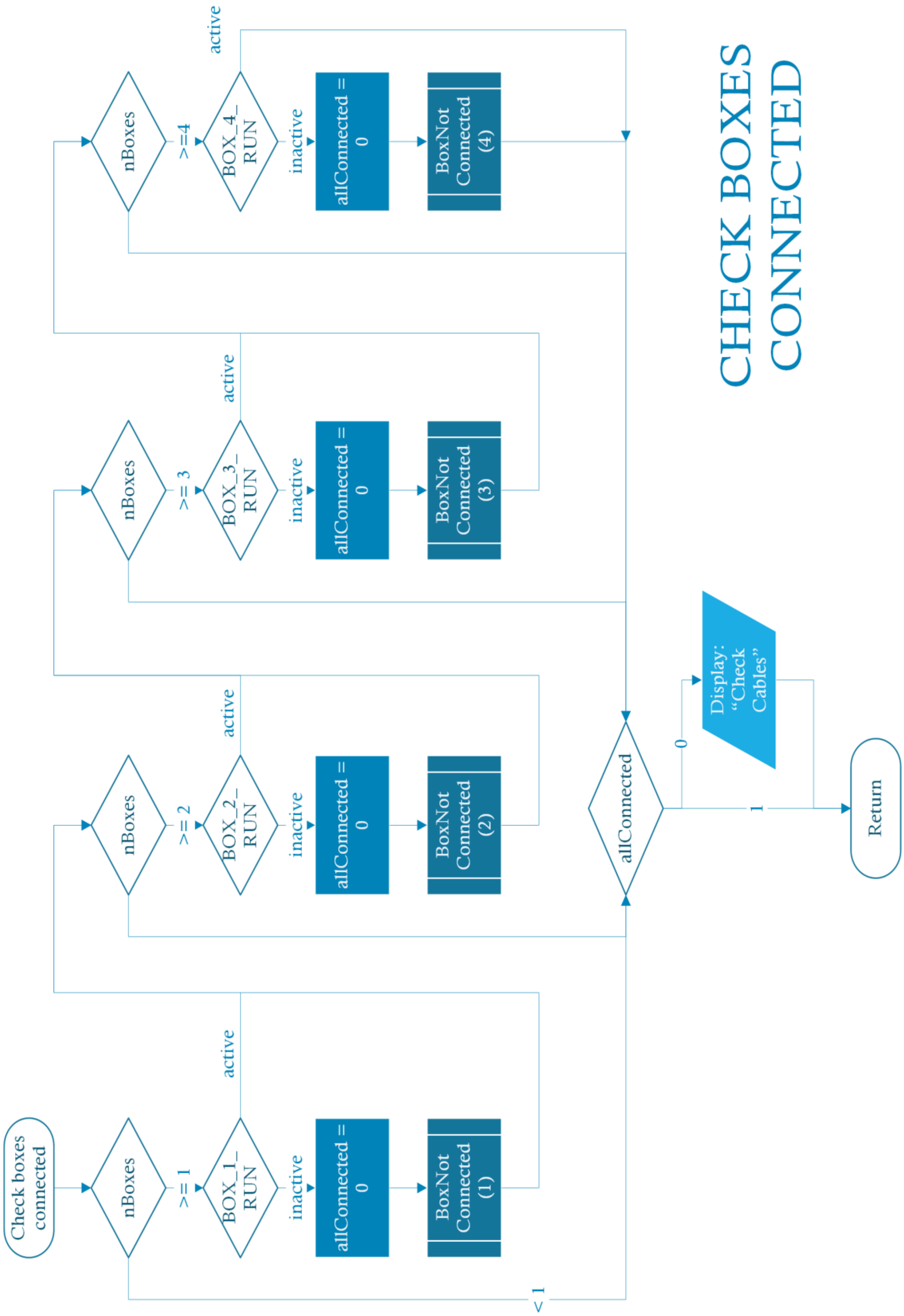


Figure 7.11: Flowchart of the process to check if all defined boxes are connected.

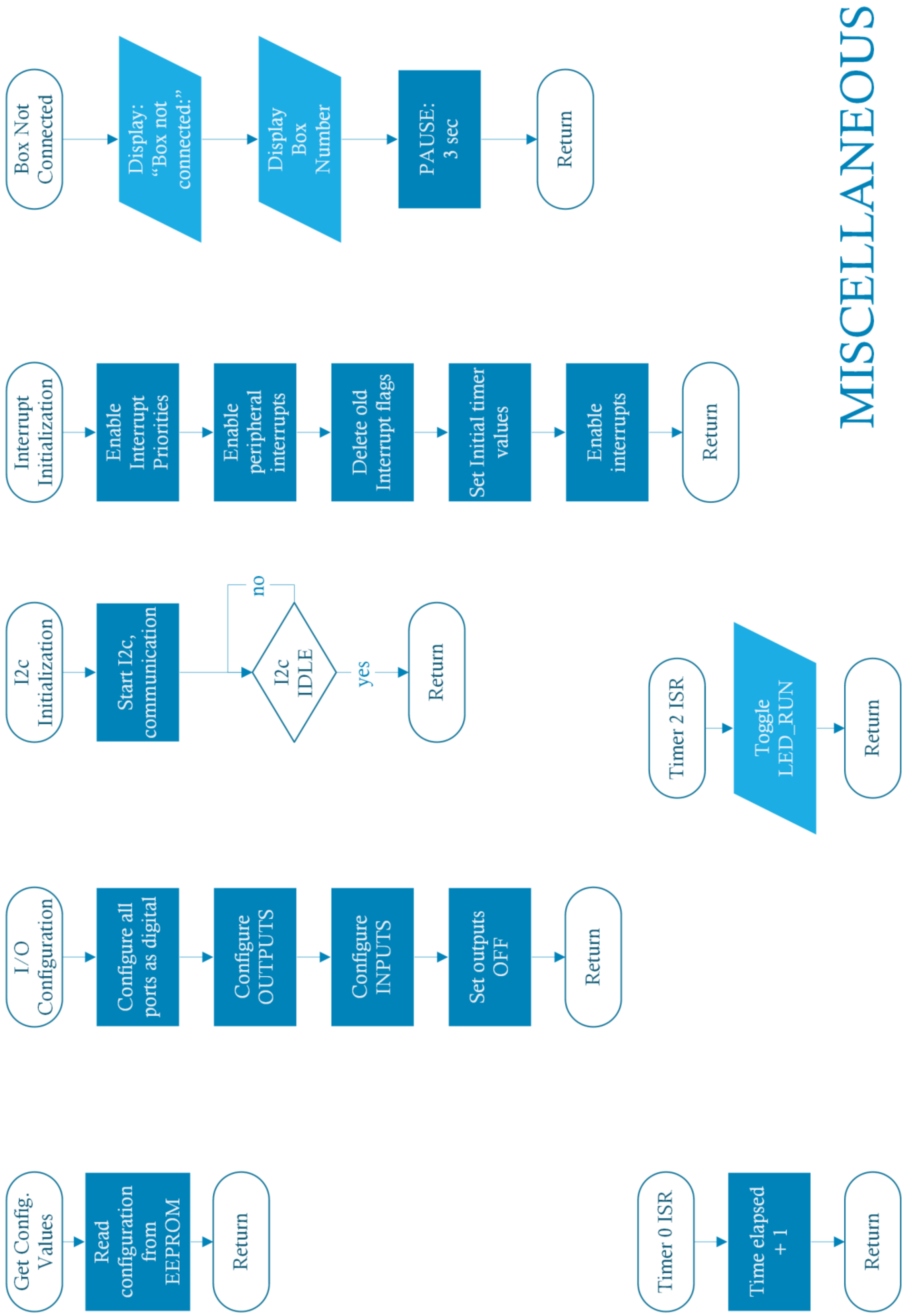


Figure 7.12: Flowchart of several used functions.

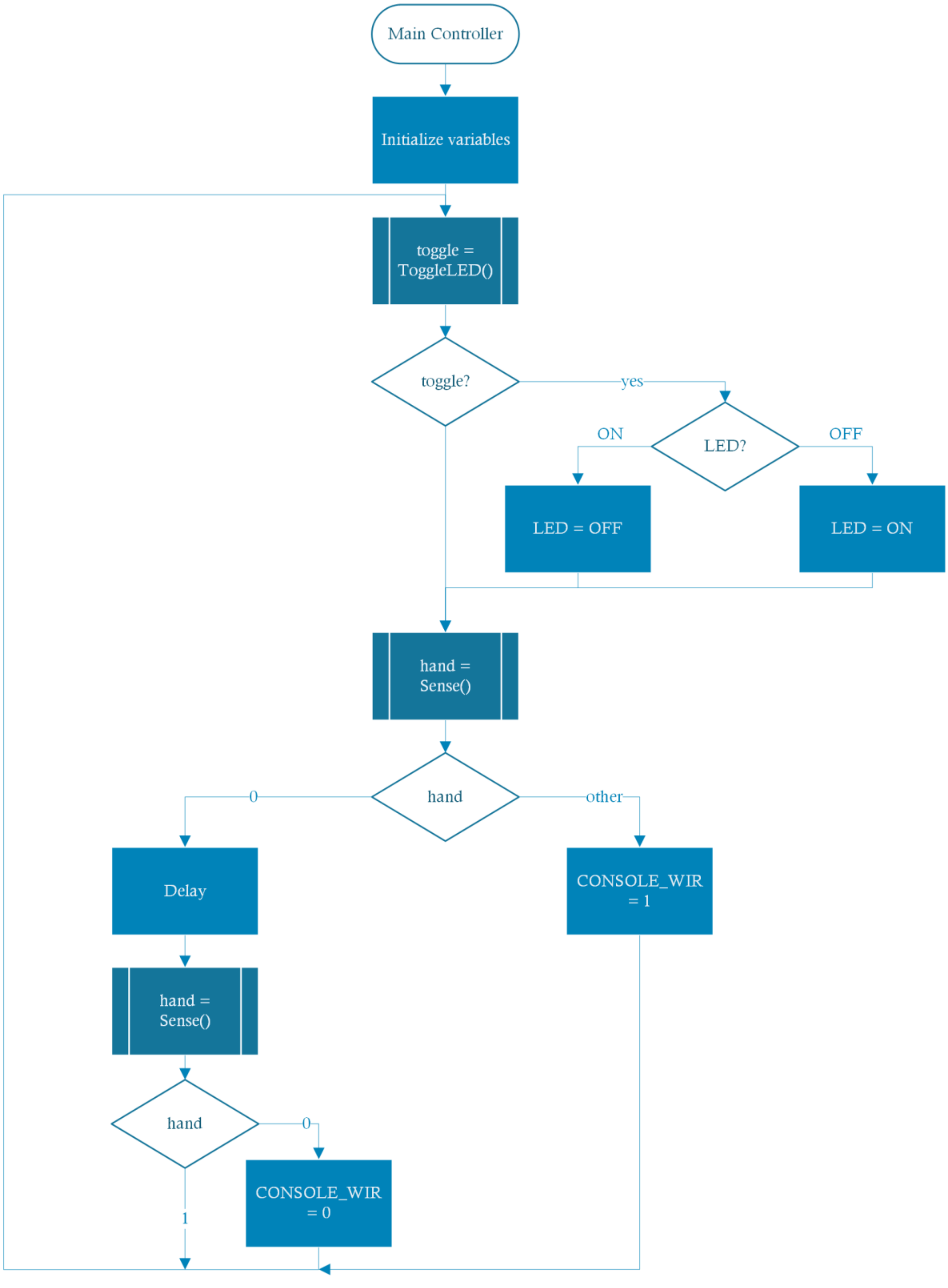


Figure 7.13 : Flowchart of the main function of the controller.

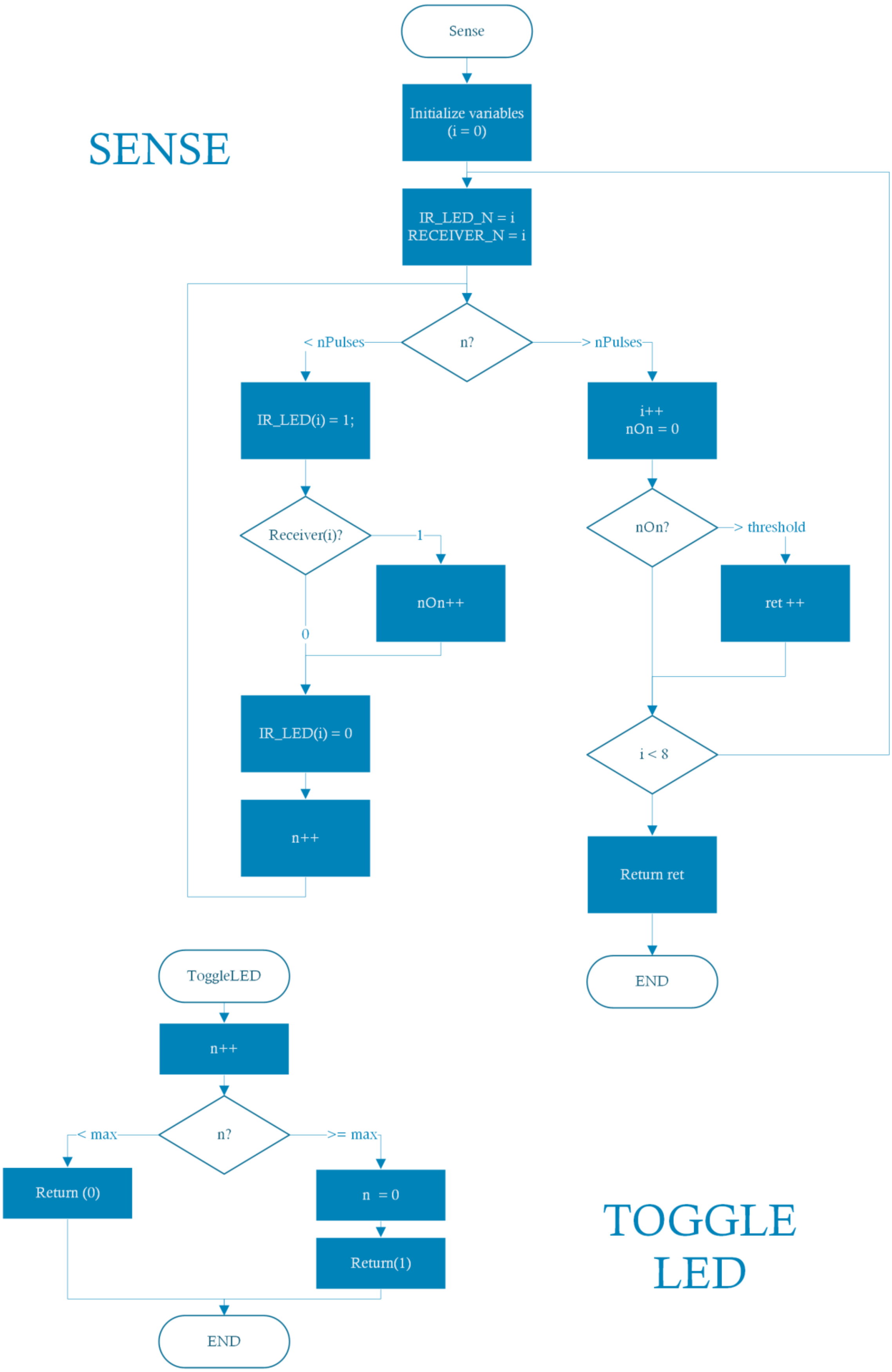


Figure 7.14: Sense and Toggle LED functions.

8. COSTS

8.1 DEVELOPMENT COSTS:

MATERIALS:

PROVIDER	ITEM	QTY.	UNIT PRICE	COST
bru y rubio	Tayg 51 box/container	1	0.8	0.8
fab lab berlin	FDM prototype Control Box Front	3	3.45	10.35
fab lab berlin	FDM prototype Control Box Back	3	3.6	10.8
fab lab berlin	FDM prototype Sensor Box Right	3	4.1	12.3
fab lab berlin	FDM prototype Sensor Box Left	3	4.1	12.3
Franz Brose	IR transparent acrylglass 9C20 sample	1	0	0
Max witte	Screw M2.5 x 10 DIN 965	50	0.05	2.5
				0
modulor	Acrylglass 120 x 250 mm	1	1.9	1.9
fab lab berlin	FDM prototype Console top	1	4.65	4.65
fab lab berlin	FDM prototype Control Box Back	1	4.2	4.2
segor	Electric Keyswitch	1	5.9	5.9
segor	Rocker switch MARQUARDT 1801.1121	2	0.7	1.4
ebay	C7 IEC power plug	5	0.85	4.25
ebay	1602 LCD screen	5	1.7	8.5
ebay	lCD I2C adapter	5	1.2	6

ebay	Keyes rotary encoder module	5	1	5
farnell	Buzzer PKM34EW-1101C/1201C	1	3.19	3.19
ebay	Solid state relay module (OMRON G3MB)	1	2.65	2.65
ebay	Coil relay module	2	1.05	2.1
microchip	PIC18F4550 sample	6	0	0
segor	Capacitor 0805 220nF	10	0.05	0.5
ebay	Transistor 2n7002	100	0.013	1.3
wago	Connector 733-334 sample	2	0	0
wago	Connector 733-336 sample	2	0	0
wago	Connector 734-132 sample	2	0	0
ebay	LED green 0805	50	0.0204	1.02
ebay	LED white 0805	50	0.0204	1.02
ebay	MINI 360 regulator	10	1.11	11.1
ebay	Pin header male 40 contacts	10	0.12	1.2
ebay	SMD 0805 resistor kit	1	6.5	6.5
segor	DIP switch 8 contacts	10	0.4	4
farnell	Power supply VTX-214-010-112	1	10.1	10.1
farnell	Power supply VTX-214-010-124	1	10.1	10.1
JST	Connector JST-SM11SB samples	6	0	0
farnell	IR LED VSMB2000	10	0.46	4.6
farnell	IR Phototransistor VEMT2000x01	10	0.66	6.6

farnell	IR Receiver TSOP77436TR	10	0.59	5.9 0
seeedstudio	PCB prototypes various 10x set	1	220	220
various	Other various	1	50	50
WORK:				
fab lab berlin	Laser cutter service (min)	0.4	30	12
designer	Mechanical Designer (h)	16	120	1920
designer	Electronic Designer, PCB development(h)	18	175	3150
designer	Embedder software programmer(h)	15	140	2100
designer	Electronics technician, PCB soldering	10	20	200
TOTAL:				7814.7

8.2PRODUCTION COSTS:

TOOL
COST:

PROVIDER	ITEM	QTY.	UNIT PRICE	COST
Protomold	Aluminium casting mold "CONTROL BOX FRONT"	1	7242.45	7242.45
Protomold	Aluminium casting mold "CONTROL BOX "	1	5146.2	5146.2
Protomold	Aluminium casting mold "SENSOR BOX LEFT"	1	4827.6	4827.6
Protomold	Aluminium casting mold "SENSOR BOX RIGHT"	1	4827.6	4827.6
Protomold	Aluminium casting mold "CONSOLE BOX TOP"	1	8116.2	8116.2
Protomold	Aluminium casting mold "CONSOLE BOX BOTTOM"	1	7815.15	7815.15
gruenwald	Pick and place programming costs (all PCB)	1	300	300
gruenwald	Stencils (all PCB)	1	200	200

PART
COST:

Protomold	Control box front (Material: ABS Black)	1000	4.31	4310
Protomold	Control box back (Material: ABS Black)	1000	2.05	2050
Protomold	Sensor box left (Material: ABS Black)	1000	1.97	1970
Protomold	Control box right (Material: ABS Black)	1000	1.97	1970
Protomold	Console box top (Material: ABS Black)	250	5.55	1387.5
Protomold	Console box bottom (Material: ABS Black)	250	4.31	1077.5
gruenwald	Console PCB including materials	250	18.55	4637.5
gruenwald	Controller PCB including materials	1000	3.82	3820
gruenwald	Emitters PCB including materials	1000	5.32	5320
gruenwald	Receivers PCB including materials	1000	4.86	4860
seeedstudio	Console box front (acrylglas laser cut)	250	0.961	240.25
seeedstudio	Console box back (acrylglas laser cut)	250	0.96736	241.84
seeedstudio	IR glass	2000	0.56	1120
TOTAL:				71479.79

SET COST:

	Control box front (Material: ABS Black)	4	4.31	17.24
	Control box back (Material: ABS Black)	4	2.05	8.2
	Sensor box left (Material: ABS Black)	4	1.97	7.88
	Control box right (Material: ABS Black)	4	1.97	7.88

Console box top (Material: ABS Black)	1	5.55	5.55
Console box bottom (Material: ABS Black)	1	4.31	4.31
Console PCB including materials	1	18.55	18.55
Controller PCB including materials	4	3.82	15.28
Emitters PCB including materials	4	5.32	21.28
Receivers PCB including materials	4	4.86	19.44
Console box front (acrylglas laser cut)	1	0.961	0.961
Console box back (acrylglas laser cut)	1	0.96736	0.96736
IR glass	2	0.56	1.12

TOTAL: 128.6584

DRAWINGS:

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